Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

CSAS
Canadian Science Advisory Secretariat

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Secrétariat canadien de consultation scientifique

Research Document 2011/059
Maritimes Region

Document de recherche 2011/059
Région des Maritimes

The Marine Ecosystem of Georges Bank

L'écosystème marin du banc Georges

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)
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Correct citation for this publication:
La présente publication doit être citée comme suit :

Kennedy, E., L. Bennett, S. Campana, K. Clark, P. Comeau, M. Fowler, C. Gjerdrum, F. Gregoire, C. Hannah, L. Harris, G. Harrison, M. James, I. Jonsen, B. Law, G. Melvin, T. Milligan, S. Paul, D. Pezzack, J. Sameoto, J. Simon, K. Smedbol, P. Smith, H. Stone, D. Themelis, L. Van Eeckhaute, J. Wade, Y. Wang, and T. Worcester. 2011. The Marine Ecosystem of Georges Bank. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/059: xiv + 232pp.

ABSTRACT

Over the past several decades, a significant amount of knowledge from scientific studies has been gathered by Fisheries and Oceans Canada (DFO), in addition to other national and international efforts, on the marine ecosystem and marine resources of Georges Bank. This research document is a compilation of DFO's most up-to-date 'state of knowledge' of the marine ecosystem of Georges Bank. The document has the following objectives under its Terms of Reference:

- description of the physical, geological/sedimentological, and biological marine ecosystem components, including marine species and at-risk species (e.g. finfish, shellfish, invertebrates and mammals);
- description of marine birds; and
- where possible, a review of existing knowledge and identification of knowledge gaps in science which, if addressed, can lead to a better understanding of the marine ecosystem of the Georges Bank area and its marine resources.

The content of this document builds on earlier reports of Gordon (1988) and Boudreau et al. (1999). This document summarizes the current state of knowledge of the marine ecosystem and marine resources of Georges Bank. Some remaining knowledge gaps have been identified, although this is not the major focus of the document. In addition, the document should not be viewed as a comprehensive review of research needs. Furthermore, the document is not to be viewed as an Environmental Impact Assessment (EIA) nor will such an assessment be provided with this document. Last, this document complements the document of Lee et al. (2011) entitled 'Consideration of the Potential Impacts on the Marine Environment Associated with Offshore Petroleum Exploration and Development Activities' (DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/060. xii + 136pp).' The Lee et al. (2011) document only considers the state of knowledge of potential impacts on marine environments associated with offshore petroleum exploration prior to April 2010. It does not consider any new knowledge or lessons that may have been learned from the Gulf of Mexico oil spill associated with the April 20, 2010, accident of the Deepwater Horizon.

RÉSUMÉ

Au cours des dernières décennies, Pêches et Océans Canada (le MPO) a acquis de nombreuses connaissances dans le cadre d'études scientifiques et d'autres initiatives nationales et internationales ayant porté sur l'écosystème marin du banc Georges et ses ressources. Le présent document de recherche dresse l'état récent des connaissances du MPO au sujet de l'écosystème marin du banc Georges. Tel qu'indiqué dans son cadre de référence, le document vise les objectifs suivants :

- décrire les composantes physiques, géologiques, sédimentologiques et biologiques de l'écosystème marin, y compris les espèces marines et les espèces en péril (p.ex., poissons, crustacés, invertébrés et mammifères);
- décrire les oiseaux marins présents dans l'écosystème;
- si possible, examiner les connaissances actuelles et déterminer quelles sont les lacunes dans l'information scientifique qui une fois comblées pourraient mener à une meilleure compréhension de l'écosystème marin du banc Georges et de ses ressources.

Le présent document fait fond sur des rapports antérieurs de Gordon (1998) et de Boudreau et al. (1999). Il résume l'état actuel des connaissances sur l'écosystème marin du banc Georges et sur ses ressources. Bien que cela n'en constitue pas le principal sujet, le document met en évidence certaines lacunes subsistant dans ces connaissances, mais il ne doit pas être considéré comme un inventaire exhaustif des besoins en matière de recherche. Il ne doit pas être considéré non plus comme une étude d'impact environnemental (EIE) et pareille étude n'y est pas présentée. Enfin, ce document complète celui de Lee et al. (2011) intitulé « Consideration of the Potential Impacts on the Marine Environment Associated with Offshore Petroleum Exploration and Development Activities » (Secr. can. de consult. sci. du MPO, Doc. de rech. 2011/060. xii + 136 pp). Le document de Lee et al. (2011) ne fait que dresser l'état des connaissances sur les impacts possibles de l'exploration du pétrole extracôtier sur les milieux marins avant avril 2010. Il ne tient donc pas compte de toute nouvelle connaissance ou leçon ayant pu être tirée du déversement d'hydrocarbures dans le golfe du Mexique ayant découlé de l'explosion du Deepwater Horizon, survenue le 20 avril 2010.

ACRONYMS AND ABBREVIATIONS

BIO	Bedford Institute of Oceanography
CITES	Convention on International Trade in Endangered Species
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	Catch per Unit Effort
CV	Coefficient of Variance
CW	Carapace Width
DDT	Dichlorodiphenyltrichloroethane
DFO	Fisheries and Oceans Canada
ECSAS	Eastern Canada Seabird at Sea
GLOBEC	Global Ocean Ecosystem Dynamics
ICCAT	International Commission for the Conservation of Atlantic Tunas
IUCN	International Union for Conservation of Nature
LFA	Lobster Fishing Area
LSW	Labrador Slope Water
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
NAO	North Atlantic Oscillation
NEC	Northeast Channel
NEFSC	Northeast Fisheries Science Center
NEC CCA	Northeast Channel Coral Conservation Area
NEP	Northeast Peak
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PIROP	Programme Integré de Recherche sur les Oiseaux Pélagiques
SABS	St. Andrews Biological Station
SARA	Species at Risk Act
SMAST	School for Marine and Science Technology
SSB	Spawning Stock Biomass
TAC	Total Allowable Catch
TMGC	Transboundary Management Guidance Committee
TRAC	Transboundary Resources Assessment Committee
U.S.	United States of America
VPA	Virtual Population Analysis
WCR	Warm Core Ring
WHOI	Woods Hole Oceanographic Institute
WSW	Warm Slope Water

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1.0 INTRODUCTION

Georges Bank is located in the offshore waters between southwest Nova Scotia and Cape Cod, Massachusetts. It straddles the Canada-United States maritime boundary, with the northeast portion of the Bank in Canadian waters. It is one of the world's richest fishing banks, characterized by a marine ecosystem of high diversity. It has been fished for more than a century by many nations, including Aboriginal peoples and First Nations, and is of major economic and social importance to many coastal communities in Canada and the United States. Other ocean users of the Georges Bank area include maritime transportation, scientific research, telecommunications, and the military. Georges Bank is also an area of interest for oil and gas exploration and development. This followed seismic surveys undertaken by the Geological Survey of Canada more than three decades ago, which identified geological formations typically associated with petroleum potential.

Offshore petroleum rights exist on Georges Bank, although they have received little attention due to a moratorium on offshore petroleum exploration and development activities in the area. The moratorium was instituted in 1988 pursuant to the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Acts (Accord Acts)*. It was set in place in response to public concern over the potential impacts of offshore oil and gas development on the Georges Bank marine ecosystem and its marine resources. Briefly, in 1988, a moratorium was placed on offshore petroleum activities (i.e. exploration, drilling, and development) on Georges Bank and much of the Northeast Channel until 2000. In December 1999, the federal Minister of Natural Resources and the provincial Minister responsible for the Nova Scotia Petroleum Directorate accepted a Review Panel's recommendation to extend the moratorium until December 31, 2012. On May 13, 2010, the governments of Canada and Nova Scotia again extended the moratorium to December 31, 2015. On December 10, 2010, however, the moratorium was extended pursuant to Nova Scotia provincial legislation entitled *Offshore Licensing Policy Act*.

Over the past several decades, a significant amount of knowledge from scientific studies has been gathered by Fisheries and Oceans Canada (DFO), in addition to other national and international efforts, on the marine ecosystem and marine resources of Georges Bank. The Georges Bank ecosystem has been a well studied marine system due in part to needs to effectively manage the commercial fisheries, international boundary disputes, oil and gas exploration interests, and the fundamental science questions relating to the physical, chemical, biological, and geological properties of the system. The presence of oceanographic research institutes in close proximity to the Bank has facilitated many scientific activities in the area (e.g. Bedford Institute of Oceanography (BIO) in Nova Scotia, the St. Andrews Biological Station (SABS) in New Brunswick, and the National Oceanic and Atmospheric Administration (NOAA) Fisheries, School for Marine and Science and Technology (SMAST), and the Woods Hole Oceanographic Institute (WHOI) in Massachusetts, as well as several other academic institutions). As a result, the Georges Bank marine ecosystem is relatively well understood compared to many other continental shelf regions throughout the world. There are many detailed descriptions of the Georges Bank ecosystem, such as that of Backus and Bourne (1987), Wiebe and Beardsley (1996), and Boudreau et al. (1999).

This document has the following objectives under its Terms of Reference:

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- description of marine birds; and
- where possible, a review of existing knowledge and identification of knowledge gaps in science which, if addressed, can lead to a better understanding of the marine ecosystem of the Georges Bank area and its marine resources.

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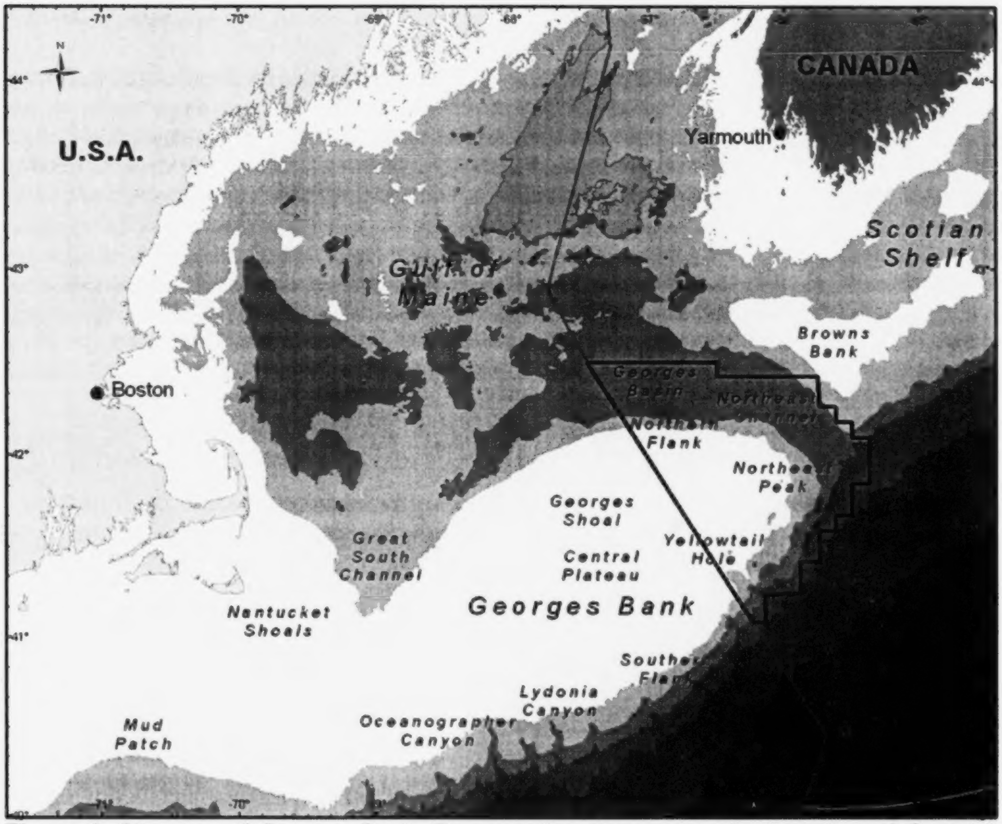
2.0 GENERAL TOPOGRAPHY

Georges Bank (the Bank) is a submarine bank located between the southwestern tip of Nova Scotia and Cape Cod, Massachusetts (Figure 1). The top of the Bank has an area of approximately 28,800 km^2 above the 100 m isobath, while the top and the sides of the Bank have an area of approximately 43,000 km^2 above the 200 m isobath (Collie et al., 2009). The Canadian portion of Georges Bank, sometimes referred to as the Northeast Peak, accounts for less than 50% of its total area (approximately 7,000 km^2). Georges Bank is connected to the deep ocean through a series of submarine canyons on the southern edge (Figure 2). The Canadian moratorium area covers approximately 15,000 km^2 and includes both Canada's portion of Georges Bank and much of the Northeast Channel.


-71°
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CANADA
Yarmouth
U.S.A.
Scotian Shelf
Gulf of Maine
Browns Bank
Boston
Georges Basin
Northeast Channel
Northern Flank
Northeast Peak
Georges Shoal
Yellowtail Hole
Central Plateau
Great South Channel
Georges Bank
Nantucket Shoals
Southern Flank
Lydonia Canyon
Oceanographer Canyon
Mud Patch

Figure 1. *Site map of Georges Bank. The grey line demarcates the boundary of Canada's exclusive economic zone and the black line demarcates the moratorium area on offshore petroleum activities.*

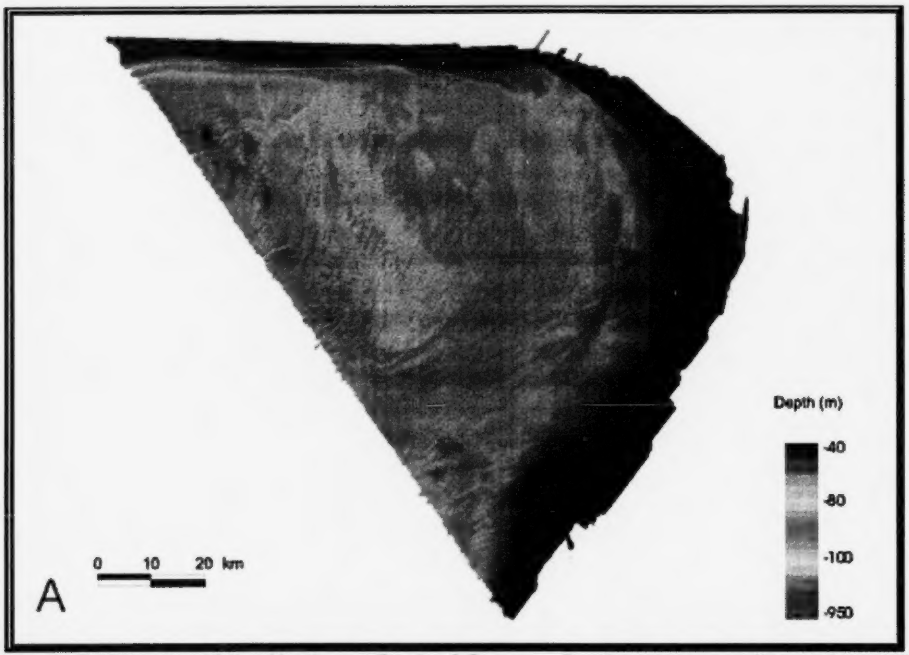


Figure 2. *Bathymetry of the Northeast Peak of Georges Bank and surrounding waters collected using a digital multibeam bathymetric sounding approach (Kostylev et al., 2005). Depth is in metres (m) below the mean sea surface level.*

Georges Bank is bounded on the west by the Great South Channel, with a depth of 70 m, on the north and east by the Gulf of Maine and the Northeast Channel, with depths near 300 m, and on the south by the continental slope (Incze, 1998; GOMA, 2010) (Figure 1). Rugged canyons, which range by as much as 1 km in depth, incise the southern edge of the Bank. The sides of the Northeast Peak are steeply sloped, exhibiting changes in water depth of more than 100 m over less than 10 km distance. The deep offshore channels that run along the ends of the Bank (i.e. Northeast Channel and Great South Channel) provide pathways for significant subsurface flow into and out of the Gulf of Maine, respectively. The average water depth across the top of the Bank is 75 m (Incze, 1998; GOMA, 2010), although this varies from an area of shallow shoals on the United States portion of the Bank to deeper waters between 60 and 100 m depth on the Northeast Peak.

3.0 CIRCULATION, HYDROGRAPHIC STRUCTURE, AND MIXING

The movement of water and marine particles (e.g. sediment or organic particles such as phytoplankton) on Georges Bank is primarily driven by tidal currents, but also by wind and variation in water density (Butman et al., 1987; Flagg, 1987; Naimie et al., 1994). The movement of water resulting from these forces is mediated by the region's bottom topography. The location of Georges Bank at the mouth of the Gulf of Maine and Bay of Fundy tidal system, coupled with its shallow depth, gives rise to strong tidal currents. The strongest currents are associated with the semidiurnal M2 tide, which exhibits a periodicity of 12.4 hours. This is near a resonance condition in the Gulf of Maine and Bay of Fundy (Garrett, 1972).

Tidal current velocities range from approximately 0.2 m s^{-1} in deeper water around the perimeter of the Bank to more than 1.0 m s^{-1} on the top of the Bank (i.e. the central plateau) (Moody et al., 1984; Xue et al., 2000). Strong, spatially-uniform M2 tidal currents cause water parcels to undergo semidaily elliptical excursions, with major axes ranging from a few kilometers in deeper water to over 15 km on the central plateau (Figure 3). As a result, to first order, any buoyant or neutrally-buoyant material that is released into the water column from a fixed point on the Bank is carried within hours over distances comparable to that of the local tidal ellipses (in reality the pathways are complicated by nonuniformity of the M2 field and by other constituents of the flow field). Similarly, any material on the sea floor is susceptible to the movement of large volumes of sea water, as well as associated physical forces such as shear stress.

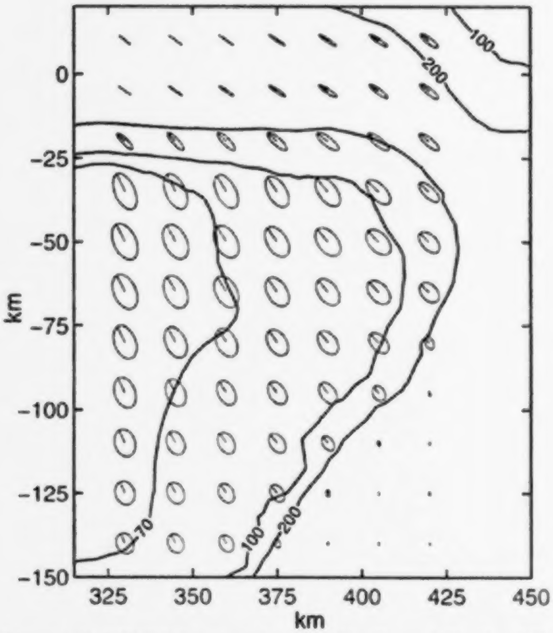


Figure 3. *M2 tidal excursions of Northeast Peak of Georges Bank based on depth-averaged tidal velocities estimated from the 3-D circulation model of Naimie (1996). Tidal ellipses, traced by the tip of the tidal velocity vector over one cycle, are drawn to the scale of associated water parcel excursions (small ellipses). The radial lines indicate common phase (small lines inside the ellipses). Bathymetry is in metres (m) the mean sea surface level (solid black lines).*

The general circulation pattern on Georges Bank is a partial, anticyclonic gyre (i.e. water rotates in a clockwise direction around the Bank) (Figure 4, upper panel). This persistent year-round circulation is associated primarily with non-linear interactions of the tidal currents over the Bank's topography. Water velocities associated with the gyre are typically 0.1-0.2 m s^{-1}, but increase to 0.2-0.4 m s^{-1} along the Bank's northern edge (Butman et al., 1987; Naimie et al., 1994; Naimie, 1996). Higher water velocities usually occur in the summer season. This seasonal intensification is primarily associated with horizontal density gradients in the frontal system. The mean flows associated with the gyre are generally strongest in the upper half of the water column and significantly decrease towards the seafloor.

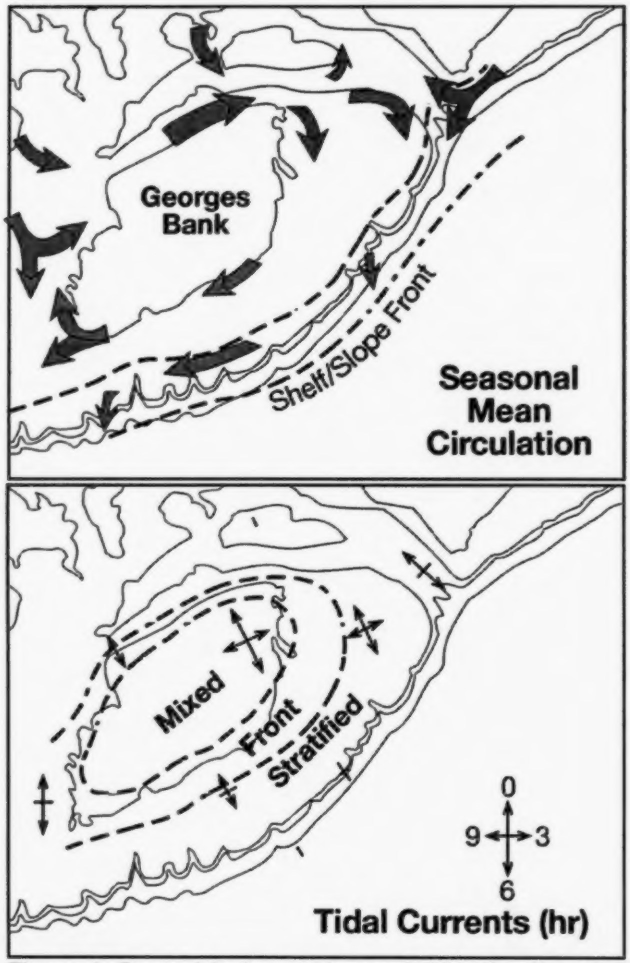


Figure 4. *General hydrographic structure and seasonal mean circulation pattern observed on Georges Bank. The upper panel exhibits the mean seasonal circulation (arrows) and the extent of the shelf water/slope water front observed throughout the year (dashed lines). The lower panel exhibits tidal current patterns (arrows) and the extent of the seasonal tidal-mixing front observed during peak summer stratification (dashed lines).*

The gyre is described as 'partial' because the recirculation of the flow around the Bank has a strong seasonal dependence and is subject to disruption by energetic transient events, such as storms and the impingement of warm core rings (WCRs) from the Gulf Stream on the offshore edge of the Bank. The seasonal behaviour of the gyre is produced by the onset of stratified conditions in the summer (July-October) and the establishment of the tidal mixing front, which bounds the well-mixed water on the cap of the Bank (Figure 4, lower panel). During summer, near-surface recirculation is established with the setting up of northward flow in the Great South Channel, which persists until winter approaches in November (Namie et al., 2001). The minimum summer recirculation time is estimated to be 40 days. Outside the summer season (e.g. March-June), recirculations are rare, but when they do occur they generally require much longer periods to complete the circuit (i.e. 80-130 days).

At all times of the year, the gyre tends to be 'leaky', in the sense that strong, episodic forcing (e.g. by winter storms) produces a significant exchange of water and associated particles with the surrounding waters of Browns Bank, Gulf of Maine, and the adjacent continental slope (Butman and Beardsley, 1987) (Figures 5 and 9). One of the most effective of these mechanisms is the impingement of large-scale (i.e. 100-200 km cross-sectional distance) WCRs, which are isolated eddies that 'pinch off' of the Gulf Stream and move into the slope water regime that lies between the Gulf Stream and the continental shelf (Smith, 1978). In the region between 60° and 70°W, WCR formation is thought to be induced by the Gulf Stream's encounter with the New England seamounts that cause meanders that rapidly grow to form WCRs. The frequency of WCR events is estimated to be 5-6 per year in the zone 60°-70°W (Lai and Richardson, 1977; Smith, 1978). Once formed, WCRs generally drift westward along the continental slope, impinging frequently on the edge of the shelf where they can exchange large volumes of water mass, heat, and salt. After a period of the order of 6 months to one year, WCRs tend to dissipate or are reabsorbed by the Gulf Stream in the western end of the slope water domain.

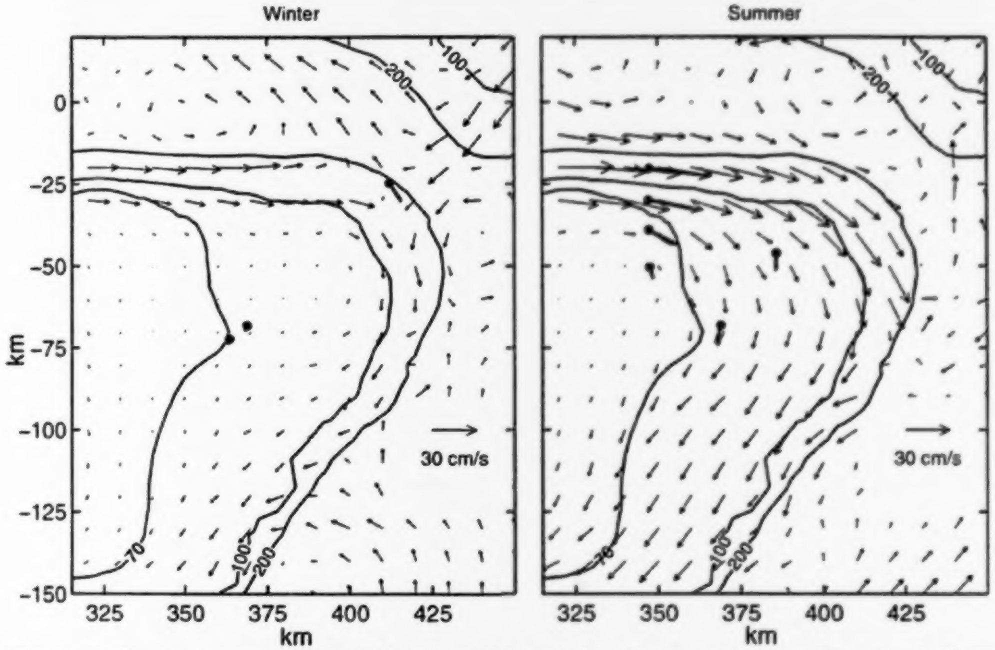


Figure 5. *Modeled mean water velocities at 20 m below the mean sea surface level of the Northeast Peak on Georges Bank for winter (January-February) and summer (September-October) seasons. Model estimates are from the 3-D circulation model of Naimie (1995). The magnitude and direction of flow are represented by the length and orientation of the thin vector arrows. Bathymetry is in metres (m) below the mean sea surface level. Observed seasonal mean water velocities from moored measurements at 10-50 m water depth are represented by the thick vector arrows. Observations are from the July to August summer period.*

Vertical mixing, bottom stress (and hence sediment transport), and the generation of seasonal mean currents observed on Georges Bank are primarily due to tides. Energetic vertical mixing associated with strong tidal currents observed on the Bank's central plateau (Garrett et al., 1978) results in the uniform distribution of temperature, salinity, and density throughout the water column in water depths less than approximately 60 m (Figure 4, lower panel, 'Mixed'). The largest variation in hydrographic properties is observed in the persistent shelf-edge front between cooler and fresher shelf waters and the warmer and more saltier slope waters (Flagg, 1987) (Figure 4, upper panel, 'Shelf/Slope Front').

In the winter, increased wind-driven mixing coupled with cooling surface waters results in well-mixed waters observed throughout the water column to depths of 100 m (Figure 6). The hydrographic properties (i.e. temperature, salinity, and density) of these waters become similar to those observed in ambient shelf regions. In the spring, seasonal heating of surface waters results in the development of strong upper ocean stratification around the Bank, with a seasonal tidal-mixing front observed over the Bank's edges (i.e. a transition zone between mixed and stratified waters) (Page et al., 2001) (Figure 4, lower panel, 'Front'). The interannual variability of the stratification of water above the sides of the Bank can be large (Bisagni, 2000). In addition, the vertical structure associated with the seasonal frontal system can be complex, with internal waves, small scale turbulence, and surface convergence. The seasonal progression of the front is shown by the density difference between surface waters and waters at 50 m depth, or the bottom if shallower than 50 m, over the course of the six bimonthly periods shown in Figure 6. The figure indicates that the front is most intense in the summer, when its width varies from 15-20 km over the Bank's northern edge and up to 40-50 km over the Bank's Northeast Peak. Furthermore, an increased speed of water as it spreads across the Northeast Peak, especially in the summer (Figure 5), is associated with the seasonal on-bank migration of the tidal front.

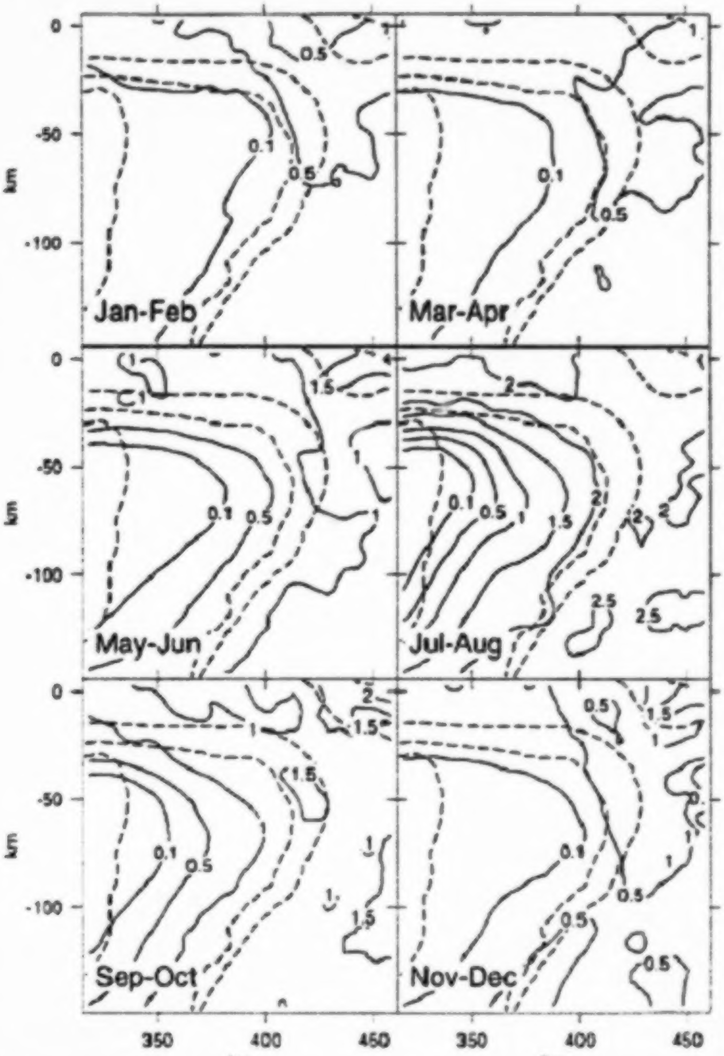


Figure 6. Differences in density (kg m^{-3}) between surface waters and waters at 50 m depth, or the bottom if shallower than 50 m, on the Northeast Peak of Georges Bank (solid lines represent density differences in 0, units). Estimates are for six bimonthly periods of a modeled year. Differences were estimated from the 3-D circulation model of Naimie (1995) using historical input data (Hannah et al., 1996). The dashed lines represent the 60 m. 100 m, and 200 m isobaths observed on the Bank, similar to those observed in Figure 5 above.

Frontal processes are important factors in both the retentive and dispersive characteristics of the Northeast Peak during much of the year (i.e. spring to fall). They have been the focus of much DFO research in the 1990s, which has improved the quantitative description and understanding of hydrographic structure, vertical mixing, internal waves, circulation, surface convergence, and dispersion in the frontal zone of Georges Bank (e.g. Loder et al., 1993). In particular, new field measurements have revealed the structure and extent of small-scale and intermediate-scale frontal zone features, illustrated schematically in Figure 7. The Northeast Peak frontal zone can be conceptualized as a hybrid, exhibiting characteristics of both tidal-mixing and bank-edge fronts (Loder et al., 1992).

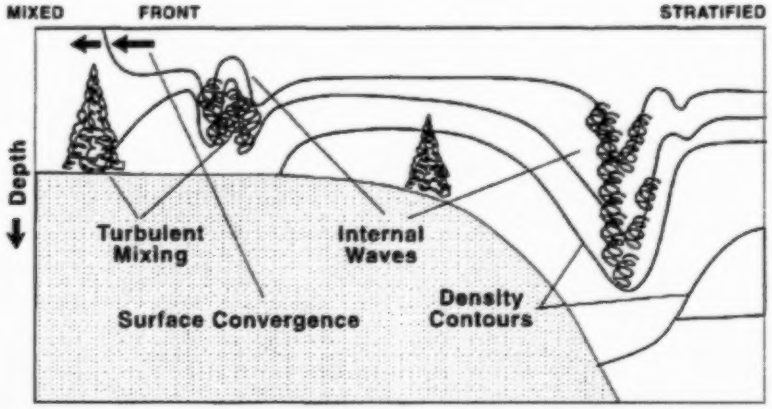


Figure 7. *Schematic representation of the vertical structure associated with the seasonal frontal system over the northern edge of the Northeast Peak of Georges Bank. The structure of internal waves, small-scale turbulence, and surface convergence are represented.*

The combined effect of the seasonal mean circulation pattern (i.e. partial gyre), tidal currents, and the near-surface convergence in the frontal zone are illustrated by the movement of three near-surface drifters at 20 m depth below the surface, deployed on the northern part of Georges Bank on July 27, 1989 (Figure 8). The drifters moved in close proximity to each other following release and circulated eastward in a spiral pattern due to the tidal ellipses and frontal-zone jet observed in this region of the Bank. Over the two day deployment period the drifters traveled more than 100 km, but they were recovered only approximately 20 km from their release points in a straight line distance. Upon recovery, the drifters were less than 2 km apart. The trajectory data illustrated in Figure 8 was obtained in the absence of strong weather systems or other short-term perturbations that typically affect the average current patterns of the Bank.

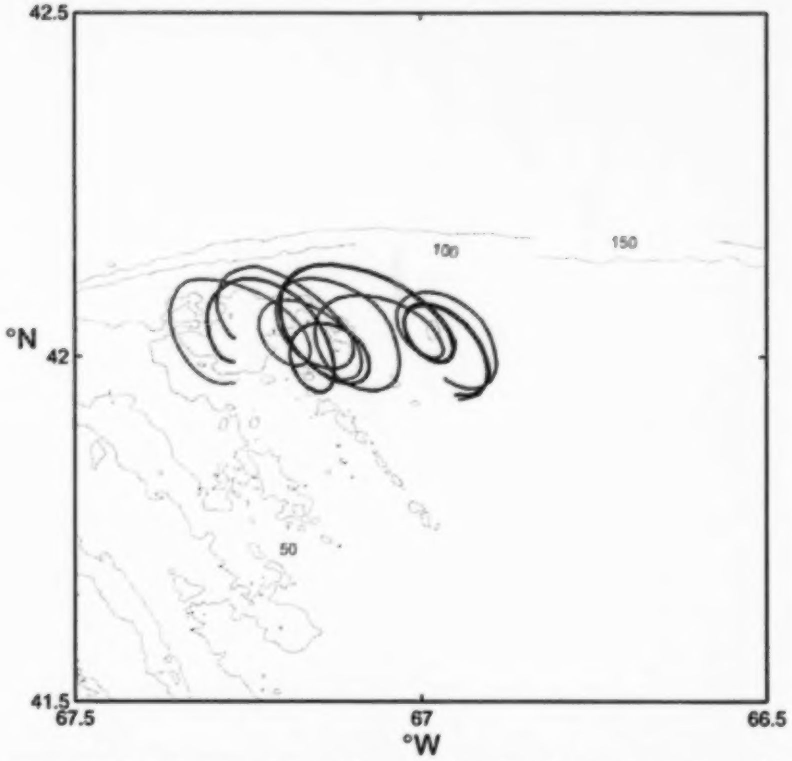


Figure 8. *Trajectories of three drifters deployed on the northern edge of Georges Bank on July 27, 1989. Over the two day deployment period the drifters traveled eastward more than 100 km, but were recovered only approximately 20 km from their release points in a straight line distance. Upon recovery the drifters were less than 2 km apart from each other. Bathymetry is in metres (m) below mean sea surface.*

Other current components are believed to perturb the basic seasonal mean circulation pattern (partial gyre) and tidal currents that dominate circulation on Georges Bank (Butman and Beardsley, 1987). Such perturbations include: 1) tidal components that result in daily, biweekly, and monthly modulations of tidal current magnitude (due to interactions with diurnal and other semidiurnal constituents) and basic shape of the semidiurnal variation (due to higher harmonics such as M4); 2) low frequency current fluctuations that exhibit periods ranging from hours to weeks (due to winds, eddies, and other offshore forcing), which are generally strongest in the upper ocean; and 3) high-frequency current fluctuations with periods ranging from seconds to an hour associated with surface waves, internal waves, and turbulence in the wind-driven surface layer or bottom boundary layer.

Temporal and seasonal variations in the currents of Georges Bank influence various particle retention and dispersion/dilution processes, which themselves vary by spatial position, season, and the occurrence of storms and other episodic events. Rates of dispersion of passive particles on the Bank are characterized by 'residence times', which represent the period over which an initial concentration of particles in a given area is reduced by a fixed fraction (usually represented by the e-folding decay time, e^{-1}), due to natural mixing/dispersion processes. As such, the higher the dispersion rate the lower the residence time and vice versa. The same factors are related to the rate at which a small cluster of particles in such an environment naturally disperse (i.e. spread and dilute) about a centroidal position. Robust estimates for the residence time of passive particles on the Bank, or parts of the Bank, have not been determined. Drifter and model studies suggest that the general residence time of passive particles on the Bank range from 20-80 days, with a strong dependence on the horizontal and vertical release position (Flagg et al., 1982; Page et al., 1998). Other important factors determining extended residence times include the Bank's size and tendency of the seasonal mean circulation to move around rather than across the Bank.

According to some model efforts and drifter studies, the longest residence times are expected for passive particles located on the central Bank, in the lower water column, and in the frontal zone in summer when the gyre circulation pattern inside the 70-m isobath tends to be closed (Limeburner and Beardsley, 1996). The shortest residence times are expected for passive particles located on the Bank's edges, in near surface waters in the winter, and over the outer southern edge of the Bank in summer (Werner et al., 1993; Hannah et al., 1998). Other modeling studies, however, have indicated that there can be important deviations from this pattern, such as the convergence of surface drifters on the central Bank during wind events (Hannah et al., 1998; Drinkwater and Loder, 2001). On the Northeast Peak of Georges Bank, available data indicate that the weakest drift (and hence greatest residence time) occurs at depth on the shallow plateau in winter and spring, when the seasonal mean circulation across the plateau is weak (Loder et al., 1998; Page et al., 1998).

Dispersion/dilution rates of particles and organisms on the Bank depend on buoyancy and active mobility (e.g. swimming), local vertical mixing rates, and local horizontal dispersion rates (including the effects of convergence zones). Strong currents and associated horizontal shears are expected to contribute to relatively high rates of horizontal dispersion for neutrally-buoyant material distributed throughout the water column via mechanisms such as shear dispersion and chaotic stirring (Csanady and Magnell, 1987; Ridderinkhof and Loder, 1994). The Bank's high vertical mixing rates generally contribute to high dilution rates for neutrally buoyant particles, but they would be less effective at diluting positively buoyant particles (e.g. surface oil) or negatively buoyant particles (e.g. drilling cuttings).

Mounting evidence of frequent and widespread near-surface convergence zones on the Bank (i.e. in the frontal zone, at the Bank edge, and in the mixed central area) suggests that, for buoyant materials, the general tendency for high dispersion is often at least partially offset by the concentrating effect of horizontal convergences (Loder et al., 1993; Limeburner and Beardsley, 1996; Drinkwater and Loder, 2001; Lough and Manning, 2001). Similarly, estimates of near-surface horizontal dispersion rates on a scale of 20 km observed on the Bank in summer and fall are often smaller than those observed in other continental shelf environments (Drinkwater and Loder, 2001). These suggest that, occasionally, northeastern Georges Bank exhibits below-normal horizontal dilution rates for buoyant materials despite its strong currents (Drinkwater and Loder, 2001). In addition, the presence of active bedforms observed on the seabed over parts of the Bank can be interpreted as evidence of transient, near-bottom convergence mechanisms that affect dense, negatively buoyant materials.

While much is understood about the general physical regime of Georges Bank, the range of confounding processes and the complexity of their temporal and spatial scales make it difficult to obtain robust quantitative measurements of variables that may influence the fate of materials introduced to the Bank (e.g. marine spills). Many advances, however, have been made in observational and modeling capabilities as a result of intensive studies conducted by the U.S. GLOBEC program on Georges Bank from 1994-2000. Results of these studies have been extensively published over the past decade in journals such as Deep-Sea Research II in 2001 and the Journal of Geophysical Research in 2003.

As part of the GLOBEC program, three intensive studies were carried out regarding physical processes on Georges Bank: 1) water structure and the onset of seasonal stratification – undertaken in 1995; 2) sources, retention, and losses of water and organisms on the Bank – undertaken in 1997; and 3) cross-frontal exchange through the tidal mixing front and shelf/slope front around the eastern and southern edges of the Bank – undertaken in 1999. Many of the important processes addressed by GLOBEC are depicted schematically in Figure 9. The following paragraphs provide a summary of some of the physical oceanographic advances that were gained from the GLOBEC program:

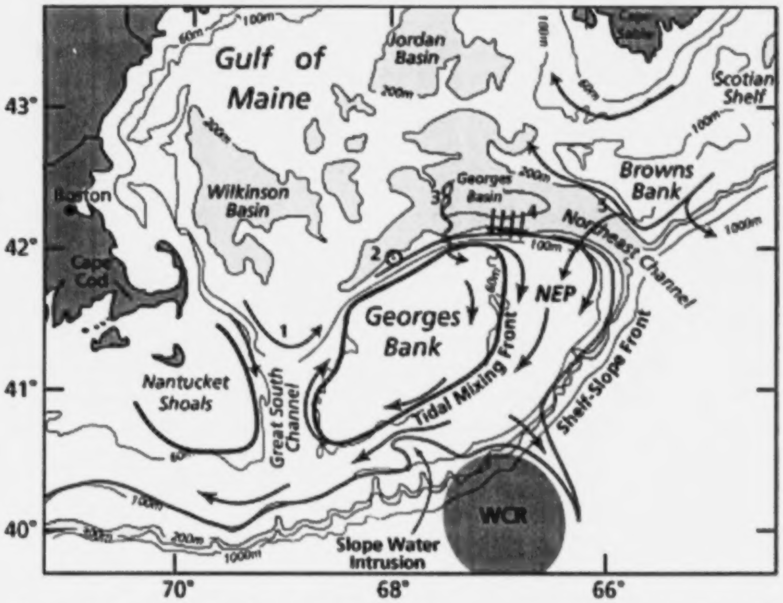

Gulf of Maine
Jordan Basin
Scotian Shelf
Cape Sable
Wilkinson Basin
Georges Basin
Browns Bank
Boston
Cape Cod
Northeast Channel
NEP
Georges Bank
Nantucket Shoals
Great South Channel
Tidal Mixing Front
Shelf-Slope Front
WCR
Slope Water Intrusion
1
2
3
4
5
60m
100m
200m
1000m
43°
42°
41°
40°
70°
68°
66°

Figure 9. Georges Bank and Gulf of Maine currents at depths less than 75 m, as depicted during the warm, stratified season (represented by the light blue and red arrows). The tidal mixing fronts around Georges Bank and Nantucket Shoals are indicated by dark blue solid lines. The shelf-slope front along the southern edge of Georges Bank is represented by the orange solid line. Northeast Peak is represented by NEP and Warm Core Ring by WCR. The WCR is shown in green off the southern edge of the Bank. The numbers in red font represent different pathways that water can get onto the northern edge of Georges Bank to start the clockwise circulation around the Bank. These are: 1) flow across the Great South Channel and eastward along the northern edge (the historical view); 2) up onto the Bank in a tidally-driven, near-bottom residual flow; 3) wind-driven, near-surface flow onto the Bank; (4) small-scale, cross-frontal processes; and 5) surface-intensified advection of water from the eastern side of the Northeast Channel known as 'Scotian Shelf Crossovers.'

Near-surface drift patterns and residence time estimates: Brink et al. (2003) examined the tracks of 203 drifters deployed on the Georges Bank that were drogued at 10 m water depth (following the work of Limeburner and Beardsley, 1996, and Naimie et al., 2001). During all seasons, they observed a clockwise flow around the Bank, with typical residence times increasing from 40 days in winter to 90 days in summer. This pattern suggested a dynamic role in the circulation pattern resulting from summer stratification, in addition to topographic rectification of the tidal currents. Apart from the gyre, primary drivers of the near-surface circulation included strong winter/spring storms and the entrainment of WCRs south of the Bank. Although difficult to discern, all of these features are evident in Figure 10a, which depicts all of the near-surface drift tracks (at 10 m depth) collected from Georges Bank and surrounding waters during the GLOBEC program. In particular, note the nearly circular paths offshelf induced by WCRs, the 'leaky' elliptical gyre feeding drifters west onto the New England Shelf, and the insertion of drifters into the gyre from Browns Bank via the 'Scotian Shelf Crossover' mechanism (Figure 10b). Paths forming the gyre are predominantly from summer deployments (Brink et al., 2003).

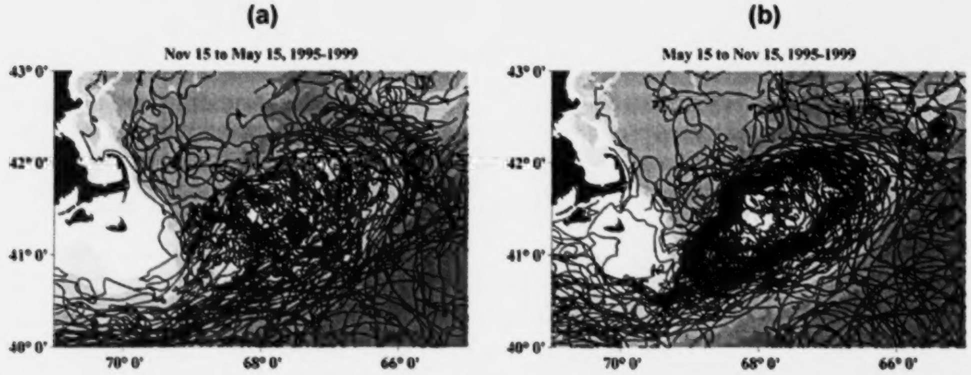


Figure 10. Near-surface drifter tracks collected on and around Georges Bank during the GLOBEC program from 1990-19'99. Panel (a) outlines winter drifter tracks and panel, (b) summer drifter tracks (images compliments of R. Limburner of Woods Hole Oceanographic Institute, Woods Hole, Massachussetts)

Effect of slope water intrusions onto Georges Bank: Based on salinity profile data from moored instruments and hydrographic surveys, Churchill et al. (2003) classified slope water intrusions as near-surface, near-bottom, or pycnocline. Each intrusion had highly-irregular horizontal structure due to wind forcing and instabilities along the front of the intruding water. Isolated cyclonic features with slope water cores suggest instability of the front of the intrusion, which appeared to be enhanced by the presence of WCRs.

Scotian Shelf Crossovers to Georges Bank: Despite the dynamical constraints of geostrophy related to the steep topography of the Northeast Channel and the retentive gyres on both Georges Bank and Browns Banks, historical data indicates that significant quantities of Scotian Shelf Water occasionally cross the Northeast Channel onto Georges Bank during the winter and spring in surface waters, above 40-60 m water depth. Bisagni and Smith (1998) demonstrated that there is significant interannual variability in the Scotian Shelf Crossover phenomenon and suggested that offshore mesoscale eddies in Northeast Channel may play an important role in triggering such events.

In the winter and spring of 1999, using a combination of moored instruments, drogued drifters, and satellite imagery, Smith et al. (2003) indicated that 20% of the drifters deployed on Browns Bank crossed the 100 m isobath of Georges Bank, exhibiting transit times ranging from 2-26 days. The maximum depth of the crossover surface water ranged from 15- 50 m and the residence time of the Scotian Shelf Crossover water on Georges Bank ranged from 3-4 weeks. Primary drivers of the crossover events appeared to be mesoscale features in the Northeast Channel, with minor influences from surface winds (Smith et al., 2003). Frequent crossover events occurred in 1999, which was a year when the Gulf Stream and shelf/slope water fronts were located to the north of there normal positions.

Wishner et al. (2003) attempted to use a biological signature to identify Scotian Shelf Crossover water on Georges Bank. They found no unique assemblages of planktonic indicator species, but they did demonstrate distinct differences in abundance and life history parameters. Population development of the target zooplankton species *Calanus finmarchicus* was found to lag that of the indigenous Georges Bank organisms, yet crossovers were thought to be the dominant source of young *Calanus finmarchicus* in early spring. Also, Dale et al. (2003) found that the internal tide on the northern edge of Georges Bank was modulated by the presence of Scotian Shelf water derived from episodic Scotian Shelf Crossovers. The lighter Scotian Shelf waters are observed to modify the tidal response by inducing mixing from internal waves, which in turn disrupt the normal spring time circulation on the Bank.

Cross-frontal exchange and mixing: Field observations indicate that buoyancy fluxes across the tidal front on the northern edge of Georges Bank are driven primarily by tidal pumping, rather than mean circulation or non-tidal eddy components (Ullman et al., 2003). The tidal flux is directed off-bank near the Bank edge and is associated with a horizontal skew flux of buoyancy along isopycnals, which is divergent at the Bank edge and convergent north of the Bank (Middleton and Loder, 1989). This phenomenon results in upwelling of dense deep water near the bottom at the Bank edge. Model studies have also contributed to our understanding of cross-frontal mixing.

Chen et al. (2003a) used a primitive equation model to identify two distinct pathways for water and associated particle movement on-bank (e.g. zooplankton): 1) over the northern edge an on-bank component of the Lagrangian residual current results in cross-frontal transport near the bottom; and 2) on the southern edge near-bottom convergence toward both the tidal mixing and shelf-slope fronts results in a divergence of near-bottom flow. Moreover, strong winter winds can drive significant off-bank transport that results in a 'washout' of Bank waters. Wind fluctuations coupled with tidal mixing plays an essential role in transporting water and particle (e.g. zooplankton) from stratified to mixed regions in early summer, when thermal stratification is in onset (Chen et al., 2003b). These processes can have important impacts on the cross-frontal flux of copepods and other zooplankton species in the region.

Interannual and decadal variability: Following the work of Petrie and Drinkwater (1993), Loder et al. (2003) demonstrated that monthly anomalies in deep water (i.e. 100-200 m water depth) temperatures on the continental slope can account for 50% of the variance of deep shelf temperatures 3-6 months later. Hydrographic sections observed during cold years in the 1950s and 1960s indicated that the anomalous conditions arose from episodic extensions of Labrador Slope Water (LSW) along the shelf break (extending from the tail of the Grand Bank to Georges Bank and beyond) followed by shelf intrusions. The extensions appear to be associated with long-term variability in the atmospheric pressure patterns over the North Atlantic, as indexed by the North Atlantic Oscillation (NAO). The NAO is due to a difference in sea-level pressure between Iceland and the Azores. In fact, sustained lows in the NAO index appear to be highly-correlated with increased transport of the LSW around the tail of Georges Bank, followed by cold, fresh intrusions into deep shelf water regions that lag by 1-2 years. The lag is due to advection timescales.

An example of such an event was described by Drinkwater et al. (1998), whereby an extreme NAO minimum in the winter of 1996-1997 was related to increased LSW transport that reached the mouth of the Northeast Channel more than two years later, in January, 1998. Figure 11 indicates the progressive arrival times of LSW on the Scotian Shelf and Gulf of Maine during this period. Figure 12 outlines LSW 'flushing' through the Gulf of Maine over a one year period. Hydrographic data from the Northeast Channel in 1999 indicates that the LSW source had been replaced by the more conventional Warm Slope Water (WSW); origin is a subtropical gyre. Changes in the relative contribution of water to Georges Bank from various sources (i.e. LSW, WSW, etc.) affect the temperature and salinity (among other properties) of the water mass (Friedland and Hare, 2007). These changes can impact processes such as nutrient cycling (Ji et al., 2008), as well as have subsequent ecological consequences such as changes to growth and reproduction of organisms.

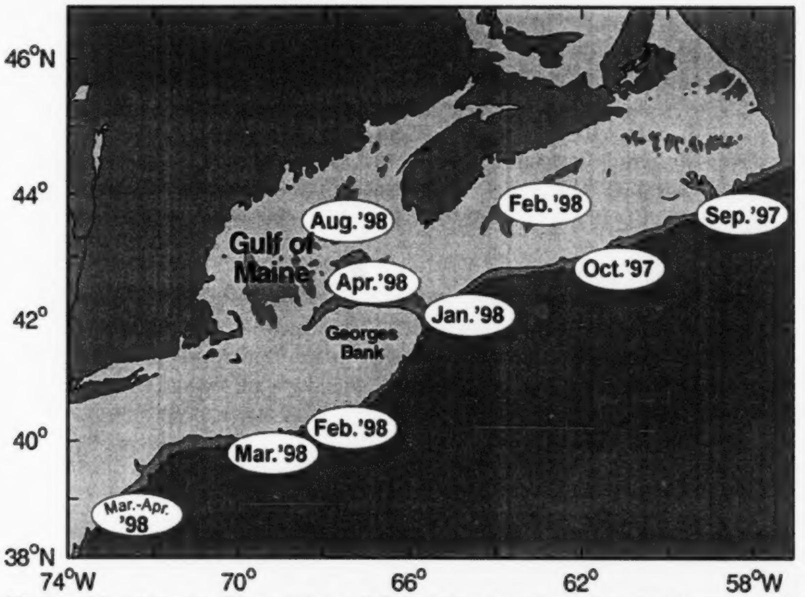


Figure 11. *Labrador Slope Water (LSW) intrusion along the shelf break and into the deep basins following the 1996-1997 North Atlantic Oscillation (NAO) event.*

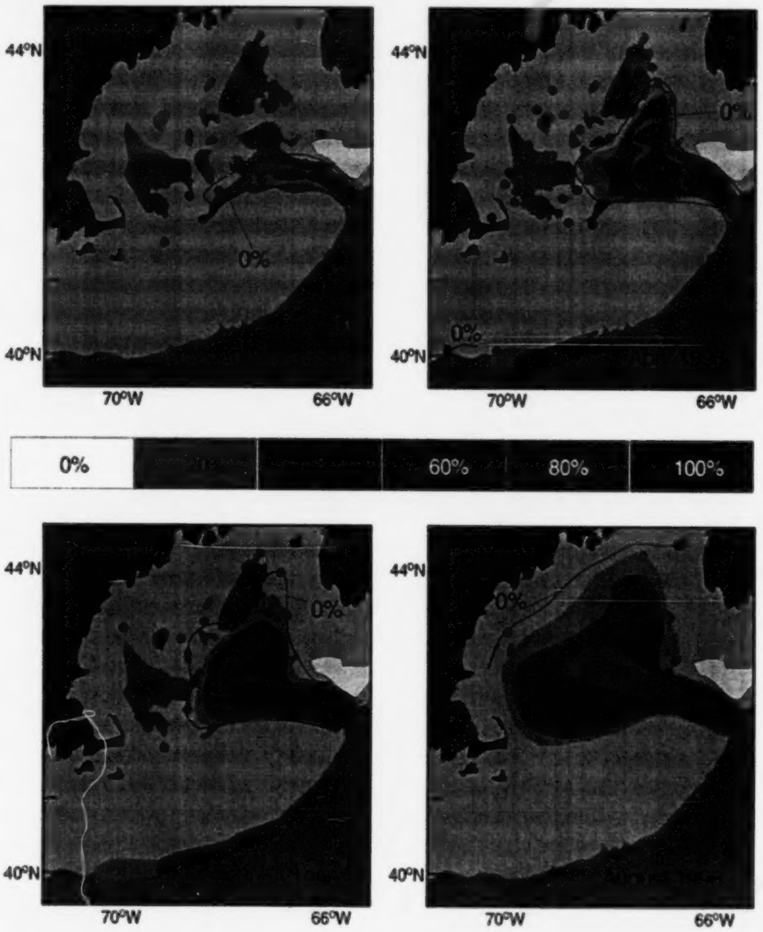

44°N
40°N
70°W
66°W
0%
0%
60%
80%
100%

Figure 12. Penetration of Labrador Slope Water (LSW) into the Gulf of Maine from January to August, 1998. Colours represent the percentage of LSW observed below 100 m water depth.

4.0 GEOLOGY

The subsurface underlying Georges Bank can be divided into four geological provinces, based on thousands of kilometres of multichannel seismic data (Figure 13). First, Long Island Platform is characterized by a seaward dipping wedge of sediments and sedimentary rock, overlying a crystalline basement complex that extends from the Fall Line to about the 3 km isopach with little or no hydrocarbon potential. Second, Georges Bank Basin is a SSW plunging structural low beneath western Georges Bank, which developed as a sag in a relatively stable platform. Much of its early sedimentation was dominated by carbonate facies, attesting to its stability and lack of significant sources of clastic sediments. Subsequent sandstone and shale facies show little variation or structure. The basin was the site of exploratory drilling in the early 1980s, with no reported occurrences of hydrocarbons. However, with a sedimentary thickness of 10 km or so and, an associated carbonate front, some potential may exist beneath the continental slope. Third, Yarmouth Arch is a south tilted basement high lying to the east of Georges Bank Basin, with little hydrocarbon potential.

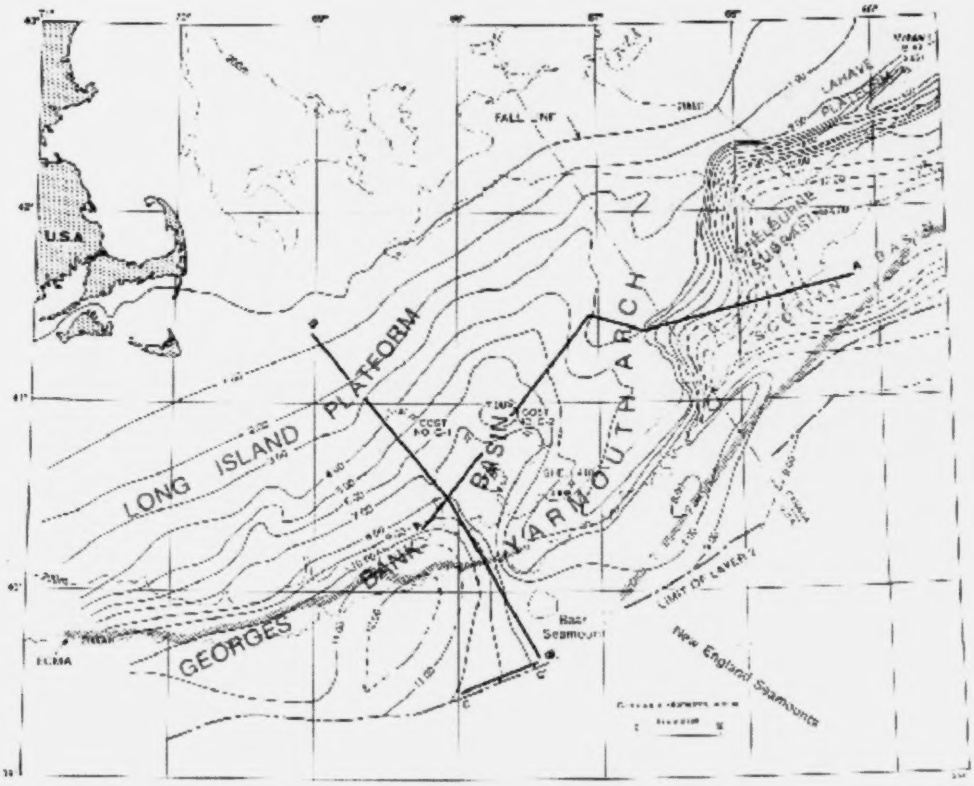


Figure 13. Depth to the breakup unconformity and major tectonic elements, Georges Bank Basin. The shaded area is the positive axis of the East Coast Magnetic Anomaly.

Last, Shelburne Subbasin is located beneath eastern Georges Bank, Northwest Channel, and the southwest corner of the Scotian Shelf. It lies almost entirely to the east of the Canada/U.S. maritime boundary. It is the western most subbasin of the Scotian Basin, which extends northeast to the western Grand Banks. In contrast to Georges

Bank Basin, Shelburne Subbasin experienced more rapid subsidence and is interpreted to contain thick deltaic sandstone facies inter-tonguing with marine shales; the source of which was a river system that drained the ancestral Gulf of Maine, Bay of Fundy, and adjacent upland areas. These deltaic beds, together with deeper water prodelta facies, overlie a thick, mobile salt unit that has resulted in the development of large down-to-the-basin fault systems and numerous diapiric salt structures (Figures 14 and 15). The prominent carbonate front, which occurs beneath much of the Scotian Shelf, is not well developed in Shelburne Subbasin due to the influx of large volumes of deltaic sediments. Significant hydrocarbon potential has been assigned to this undrilled subbasin by a number of exploration companies, as well as in resource assessments conducted by Natural Resources Canada in the 1980s. Play types, similar to those in the Sable Island area of the Scotian Shelf, are expected to occur in the Shelburne Subbasin.

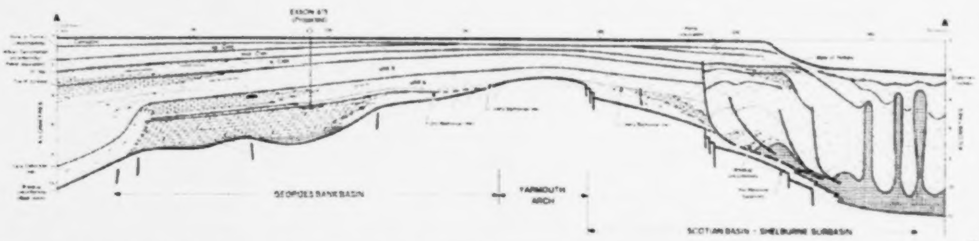

A
A'
GEORGES BANK BASIN
YARMOUTH ARCH
SCOTIAN BASIN - SHELBURNE SUBBASIN

Figure 14. Geological cross-section A-A' from Georges Bank Basin to the Scotian Basin showing stratigraphical relationships.

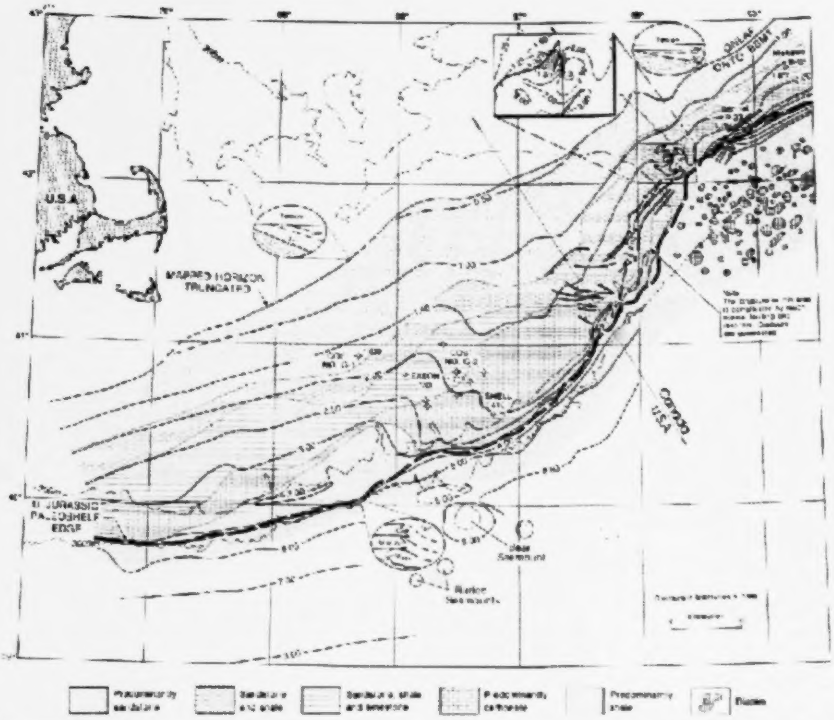

U.S.A.
MAPPED HORIZON TRUNCATED
JURASSIC PALEOSHELF EDGE
Bear Seamount
Canada-USA

Figure 15. Contours on the top of the Jurassic with generalized unit b (Upper Jurassic) facies of sequence 2.

5.0 SEDIMENTOLOGY

The surficial sediments on top of Canada's portion of Georges Bank consist of large expanses of sand substrate, interspersed with gravel and mixed sediment regions (Figure 16). Unique bottom features on Georges Bank include a permanent gravel pavement occupying the Northeast Peak. Sand waves and ripples occur over sandy areas, with the largest (up to 14 m in height) found in the northwest region of the Bank. In contrast, the relative abundance of fine sediment increases with water depth, particularly below 60-100 m depth where turbulence from tidal currents and wind waves is less pronounced. Fine sediment is most prevalent along the southern edge of the Bank, where reduced winnowing and sediment deposition likely occurs (Boudreau et al., 1999).

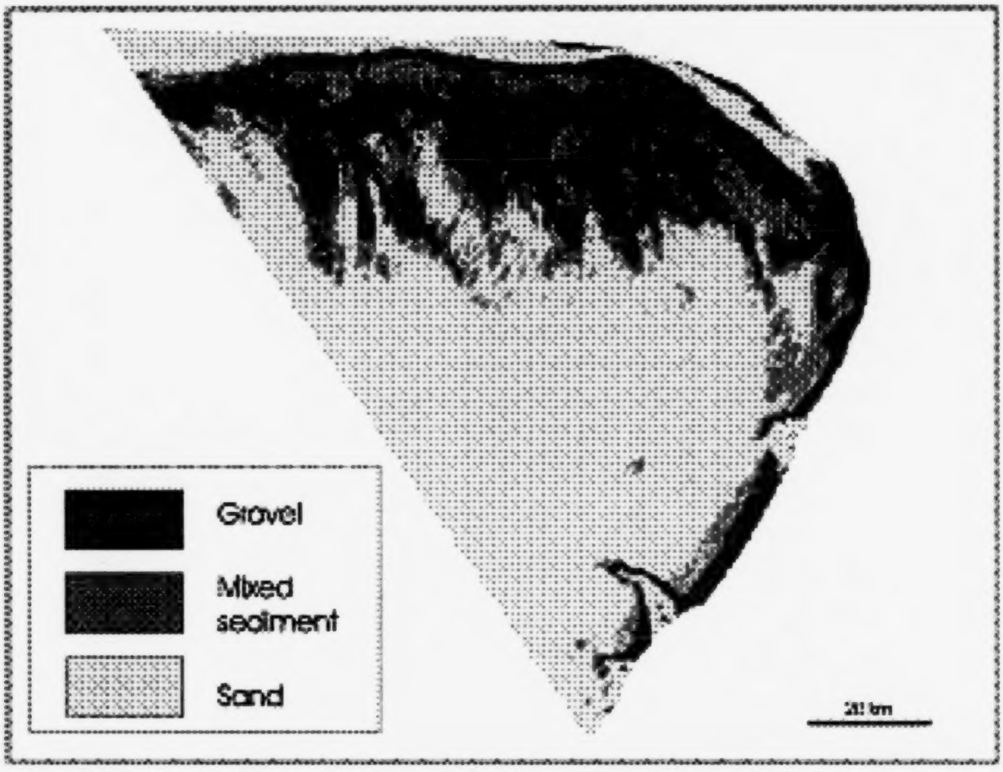


__Figure 16.__ Bottom sediment grain-size on Canada's portion of Georges Bank. Data was obtained by way of multibeam, grab sample analysis, and bottom video collected from Natural Resources Canada and the U.S. Geological Service. Sand is represented by grain sizes ranging from 0.0063-2 mm in diameter and gravel is all material greater than 2mm in diameter (Kostylev et al., 2005).

Canyons on the southern edge also export fine sediment to deeper waters, where sandy muds are found. Large glacial erratics and boulders, which increase structural complexity, can be found interspersed with the gravel. The grain size of bottom sediment is generally determined by the balance between shear stress at the bottom and the supply of sediment. On continental shelves, where sediment supply is limited, the bottom sediment grain size is primarily a function of wave height (George and Hill, 2008). On Georges Bank, however, tidal currents and Pleistocene geology also play significant roles (Shepard et al., 1934; Kostolev et al., 2005; Uchupi and Bolmer, 2008). As a result, bottom sediments on the central plateau of Georges Bank, where water depth is the shallowest and shear stress is greatest, are primarily composed of coarse sediments such as sand and gravel (Figure 16).

On Georges Bank, frictional velocities associated with strong tidal currents and waves can rework surficial sediments on the seabed, particularly during winter storm events, leading to near bottom suspended sediment concentrations on the order of 0.5-1 g L^{-1} (Backus and Bourne, 1987; Muschenheim and Milligan, 1998) (Figure 17). Factors that influence the near bottom suspended sediment concentrations include erosion and resuspension of bottom sediments and the settling and deposition of suspended sediment; a significant proportion of which is organic material (Muschenheim and Milligan, 1998).

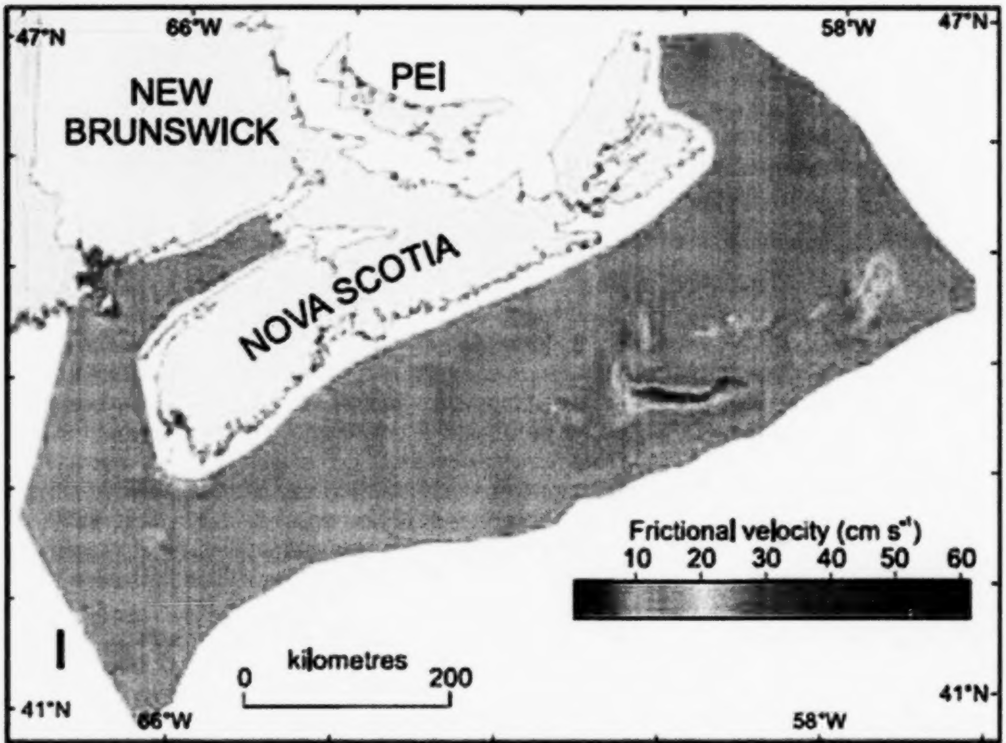


Figure 17. Frictional velocities (cm s^{-1}) in the offshore of Nova Scotia produced from tidal currents (Kostylev and Hannah, 2007).

In the near bed region, termed the 'benthic boundary layer', the vertical distribution of both particle size and concentration is a function of current shear and settling velocity of the particles. The result is a benthic boundary layer where large, fast sinking particles are found near the bottom and smaller, slow sinking particles are found upwards in the flow. The equilibrium profile of this material in suspension varies with shear stress generated by tidal currents and waves. The fact that slower sinking particles are found in areas where flow speed is higher leads to dispersion of the material. Observations demonstrate that both tidal and seasonal mean currents contribute to elevated rates of suspended sediment dispersion on Georges Bank, although the magnitude varies by location across the Bank.

Increased magnitude and spatial complexity of sediment drift and dispersion rates can be expected at times when there are strong perturbations on the basic tidal and seasonal mean flows due to other flow components such as storms and internal waves. On the Northeast Peak of Georges Bank, dispersion rates of coarse sediments (i.e. sediments moving along or just above the seabed) increase towards the centre of the Bank, where tidal currents are strongest and are the primary source of vertical shear in the near-bottom region. In contrast, the largest dispersion rates for fine grained sediment, which is suspended farther up in the water column, occurs along the northern edge of the Bank. This is due to the seasonal mean current that is the primary contributor to vertical shear at mid water depths. The depositional areas of fine grain sediment from the Bank are the Mud Patch located south of Cape Cod, Gulf of Maine, canyons along the southern edge of the Bank, and the adjacent continental slope.

The location and distribution of benthic organisms and fish on the Bank are closely linked to both sediment texture and the quality of seston (i.e. the organic material being deposited on the bottom). High rates of primary productivity found on Georges Bank and in the Bay of Fundy lead to elevated fluxes of carbon that can enhance benthic production. The combination of these factors leads to biological community relationships, including the biogenic sand-gravel and sand-shell fauna assemblages on the Bank (Thouzeau et al., 1991), presence of various coral communities associated with the coarse gravel substrates of the Northeast Channel (Mortensen et al., 2006), and the very productive scallop fishery. The gravel pavement on the Northeast Peak, which covers an underlying sandy seabed, is important for the attachment of juvenile sea scallops, nursery ground for juvenile cod and haddock, and is a habitat that provides an important food source for demersal fish (Lough et al., 1989; Collie et al., 2009).

Methratta and Link (2006) presented mean biomass of seven species generally associated with fine-grained sediments (e.g. goosefish, white hake, red hake, silver hake, witch flounder, American plaice, and thorny skate) in six substrate types in the Gulf of Maine and Georges Bank region (Figure 18). They demonstrated that these species tended to concentrate in fine sand, silt, and clay environments. They also demonstrated mean biomass of seven species generally associated with coarse-grained sediments (e.g. Atlantic cod, haddock, winter flounder, longhorn sculpin, sea raven, and winter skate) in six substrate types in the Gulf of Maine-Georges Bank region (Figure 19). Results demonstrated that these species tended to concentrate in coarse rock, fine rock, and coarse sand environments.

The substrate on Georges Bank is susceptible to a range of natural and anthropogenic activities such as storms, fishing, and oil and gas activities. For example, side scan sonar images have demonstrated disturbance to the gravel pavement by mobile fishing gear (Valentine and Lough, 1991). If sediment armoring was changed by either removing or disturbing the gravel-sized bed sediment, the sand below could be subject to erosion and transport that may blanket the surrounding gravel, resulting in changes to the local substrate composition.

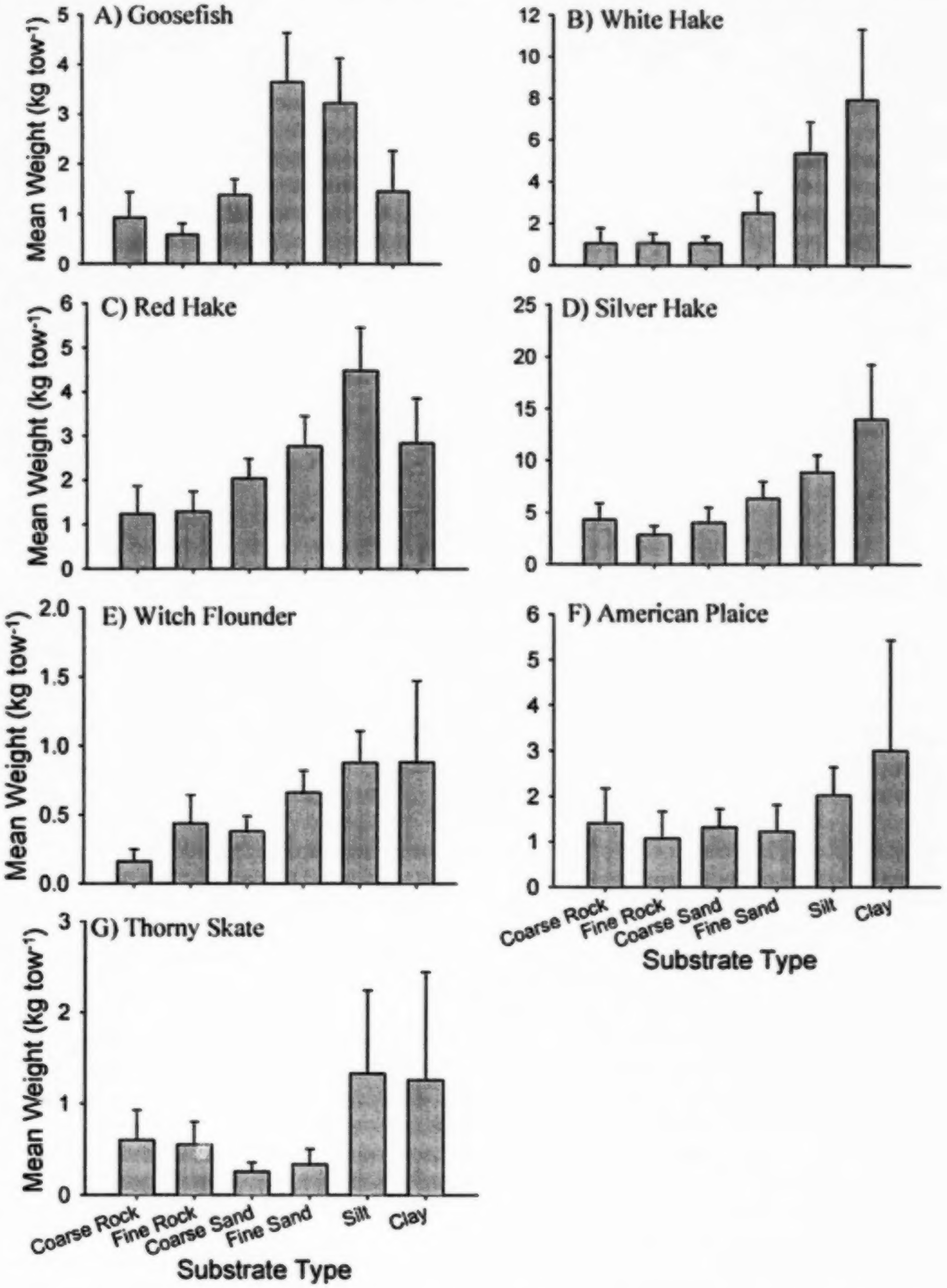


Figure 18. *Mean biomass in the Gulf of Maine and Georges Bank region (kg tow^{-1}) for select marnie species by substrate type. The species generally prefer fine-grained sediments as a substrate type. The bars represent the 95% confidence interval about the mean value (Methratta and Link, 2006).*

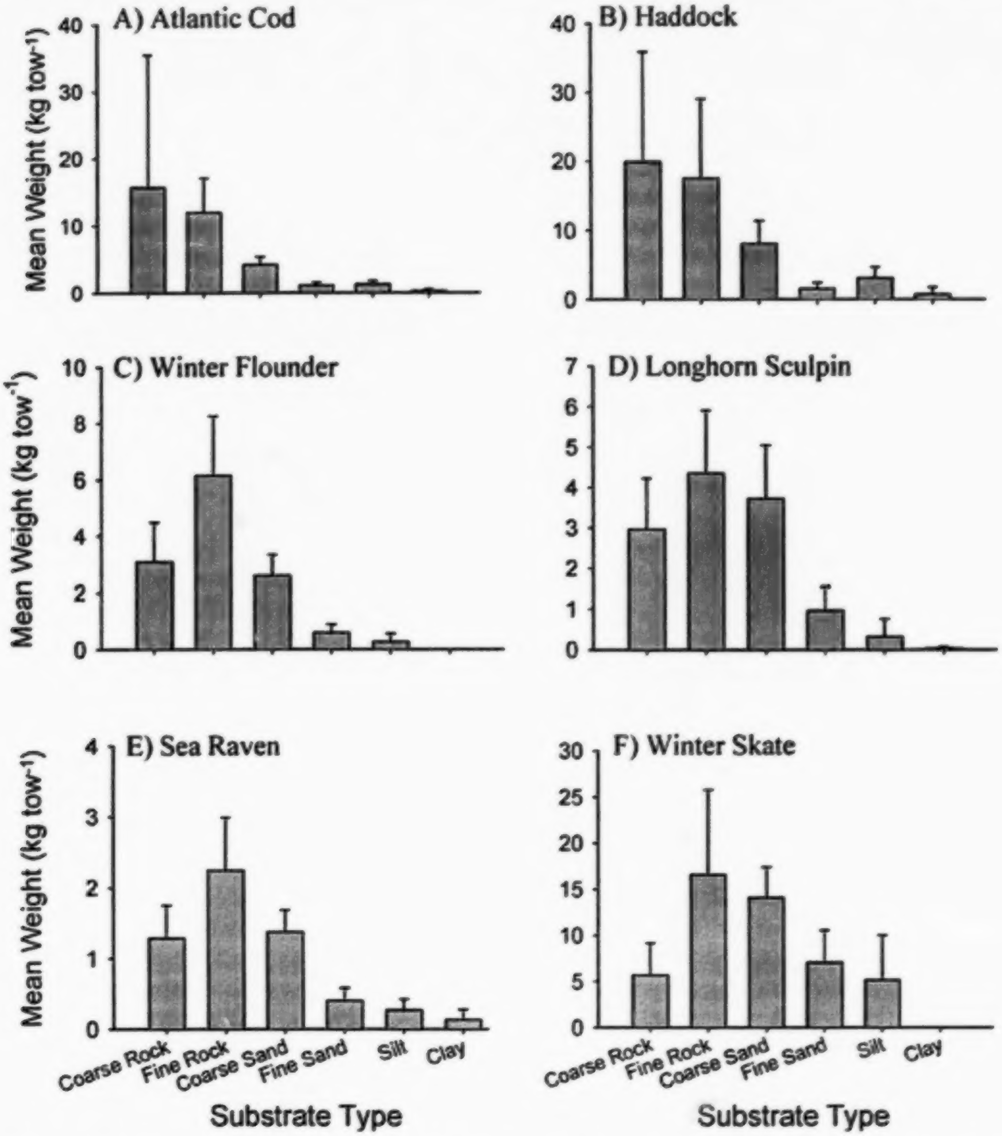


Figure 19. *Mean biomass in the Gulf of Maine and Georges Bank region (kg tow^{-1}) for select marnie species by substrate type. The species generally prefer coarse-grained sediments as a substrate type. The bars represent the 95% confidence interval about the mean value (Methratta and Link, 2006).*

6.0 TROPHIC INTERACTIONS

The Georges Bank moratorium area consists of a highly productive ecosystem. Phytoplankton and fisheries production is higher than in the neighbouring Gulf of Maine, Scotian Shelf, and North Sea (Cohen and Grosslein, 1987). Growth rates of both haddock and scallop on Georges Bank are greater than those of other northwest stocks of these species (Schuck and Arnold, 1951; Black et al., 1993). The physical attributes characterizing this area, which have been described in previous sections, contribute to its high productivity (Backus and Bourne, 1987; Boudreau et al., 1999; Franks and Chen, 2001; Wiebe et al., 2002). The fronts and gyre around Georges Bank facilitates the upwelling of nutrients on to the Bank and into the photic zone, enhancing plankton production, which propagates up the food web through to the rich shellfish and finfish populations that occupy the Bank. At 61-63 tonnes per squared kilometre (t km^{-2}), lower trophic level biomass in the Gulf of Maine and Georges Bank is estimated to be composed of 50% zooplankton, 40% primary producers (e.g. phytoplankton), and 10% bacteria (Gaichas et al., 2009).

The high primary productivity on Georges Bank supports an abundance and diversity of marine species that spend some or all of their life histories on Georges Bank. For most fish species, the spawning period is a sensitive time when the growth of eggs and larvae are susceptible to natural and human-made perturbations in the surrounding environment. Perturbations that affect the timing and rate of primary production and subsequent zooplankton production can affect the recruitment success of commercially-important species. A delay in the spring bloom by a few weeks, for example, can influence recruitment of larval fish and shellfish into the population (Cushing, 1990). Table 1 outlines the timing of various life stages for select invertebrates and commercial fish species that occupy Georges Bank.

Table 1. *Timing of various life stages for select invertebrates and commercial fish species that occupy Georges Bank (modified from Boudreau et al., 1999).*

		Month											
Species	**Life Stage**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Scallop	larvae					←	→		←	—	→		
Lobster	larvae						←	→					
Cod	spawning		←	→									
	larvae			←	—	→							
Haddock	spawning			←	→								
	larvae			←	—	→							
Yellowtail	spawning			←	—	—	—	—	→				
	larvae				←	—	—	→					
Herring	adults				←	—	—	—	—	—	—	→	
	spawning									←	—	→	
	larvae	—	—	→							←	—	—

Species of the Georges Bank ecosystem are linked through a web of trophic interactions (i.e. feeding). The Georges Bank ecosystem encompasses five trophic levels that range from primary producers and grazers to upper level predators such as sharks (Link et al., 2008), including detrital and other feedback loops. Nutrients are plentiful on Georges Bank because of offshore upwelling along the shelf-slope break and movements of slope water into the Gulf of Maine through the Northeast channel (Townsend et al., 2006). This makes Georges Bank a very productive area.

Energy is transferred through the ecosystem via trophic interactions. Georges Bank is a highly-connected ecosystem (Link, 2002), as indicated by several factors such as the spatial and temporal openness of the marine ecosystem, omnivorous and generalist feeding habits, moderate dietary overlap between species, and size-based (ontogenic) diet shifts. There is a trend toward increased piscivory with size in many species on the Bank (e.g. Atlantic cod). The dietary overlap between species is frequently higher than the overlap between size classes of the same species, as predators may vary their focus among prey depending on availability (Garrison and Link, 2000a).

There are two main energy pathways on George's Bank: pelagic and benthic. Phytoplankton is at the base of the marine food-web and the primary source of nutrition for zooplankton. Phytoplankton and zooplankton are food for larval fish and invertebrates, as well as higher level predators such as leatherback turtles, seabirds, and North Atlantic right whales. At the base of benthic pathway is detritus, which is organic waste that is generated by species that reside throughout the water column. Detritus eventually descends to the benthos. Benthic species, such as clams and other mollusks, filter phytoplankton and suspended detritus from the water column, while other groups depend on the organic content of sediments or detritus for their energetic needs that has reached the seafloor (e.g. certain species of marine worms).

Atlantic herring are a key forage species on Georges Bank and are critical to the transfer of energy from lower trophic levels to higher trophic levels (Link et al., 2008). Other mid-trophic speces include small pelagics, small demersal fish, and crustacean species such as crab and shrimp. Mid-trophic levels have an important role in the transfer of energy in marine systems (i.e. benthic and pelagic pathways) and are important prey items for fish and larger crustaceans (Link et al., 2008; NEFSC, 2009). The diet of adult cod and haddock, for example, consists of fish, crustaceans, and molluscs. The diet of halibut includes shrimp, crab, and fish, such as sand lance (Cargnelli et al., 1999; Lough, 2004; Brodzick, 2005). It has also been suggested that trophic linkages from primary production to fish include benthic populations, with suspension feeders considered a critical pathway for transfers to higher trophic levels (Boudreau et al., 1999).

Transfer to the highest trophic levels is often through pelagic pathways. The diets of porbeagle and thresher sharks, for example, consist primarily of pelagic fish. Squid, shellfish, and crustaceans are also consumed. Although fish are the dominant prey of sharks, some sharks are also planktonic consumers. For instance, basking sharks are very large slow-moving planktonic feeders with a diet that primarily consists of copepods, other zooplankton, fish eggs, and larvae. These are both examples of pelagic energy pathways between the lower trophic level and top level predators. The number and variety of connections between trophic levels demonstrates the complexity of the George's Bank marine ecosystem and highlights some of the challenges in understanding the relationships between species that occupy the region. Although there are numerous interactions, few are of the magnitude to drive whole system dynamics. Due to the dietary overlap, omnivorous, and generalist nature of species and ontogenic diet shifts of predators, it is unlikely that one species is directly impacted by populations of other species (Garrison and Link, 2000b; Link, 2002).

7.0 PLANKTON

7.1 BACTERIOPLANKTON

Bacterioplankton are prokaryotes (i.e. *Bacteria* and *Archaea*) that constitute the smallest free-living cells in any pelagic ecosystem. In the Gulf of Maine and Georges Bank region, as elsewhere in the ocean, some bacterioplankton use light as a sole or major energy source (i.e. photoautotrophs), others use light as an auxiliary energy source (i.e. photoheterotrophs), while the majority of bacterioplankton use organic material as an energy source (i.e. heterotrophs). Approximately 2% of bacterioplankton on Georges Bank are photoautotrophs (i.e. cyanobacteria), which contribute directly to primary production. Early studies to identify heterotrophic bacteria relied on laboratory isolation on agar plates, but it is known that this method recovers no more than about 1% of the total community.

On Georges Bank, abundant isolates are *Pseudomonas* and *Aeromonas* (Hobbie et al., 1987). Less abundant isolates are *Flavobacterium, Micrococcus, Planococcus, Bacillus, Enterobacter, Vibrio, Photobacterium, Alcaligenes,* and *Lucibacterium* (Hobbie et al., 1987). The vast majority of microbial diversity is resistant to culture, but can be typed by phylogeny according to gene sequences. Bacteria in the Gulf of Maine comprise the dominant SAR11 phylotype cluster (*Pelagibacter*), while other highly abundant phylotypes are the SAR86-like cluster, SAR116-like cluster, *Roseobacter, Rhodospirillaceae, Acidomicrobidae, Flavobacteriales, Cytophaga*, and unclassified *Alphaproteobacteria* and *Gammaproteobacteria* clusters (Li et al., 2009). It is estimated that there are 1.6×10^{25} prokaryotic cells throughout the water column in the entire Gulf of Maine Area, of which 1.9×10^{24} may be found on Georges Bank (Li et al., 2009). Assuming a carbon content of 10 femtograms (fg) per cell and carbon dry weight of 50%, the biomass of bacterioplankton in the waters of Georges Bank is estimated to be 37,000 t dry weight. The rate of bacterial production is estimated to be 20 $\text{mgC m}^{-3} \text{d}^{-1}$ (Hobbie et al., 1987). This is equivalent to approximately one turnover of the biomass per day.

Although the spatial distribution of bacterioplankton has not been systematically mapped on Georges Bank, a linkage to phytoplankton chlorophyll at different scales is evident from some studies. For example, for a transect across Georges Bank along its minor axis during spring, there was coherent variation of the microbial groups from transect station to station (Hobbie et al., 1987). Furthermore, at a given station, chlorophyll and bacterioplankton can exhibit parallel vertical distributions from the sea surface to the bottom of the photic zone (Figure 20). The trophic linkage between phytoplankton (i.e. primary producers) and bacterioplankton (i.e. secondary producers) is mediated through the flux of dissolved organic material derived from phytoplankton exudation, cell autolysis, viral lysis, and egesta released from grazers that have consumed phytoplankton. Although cell-to-cell interactions between microbes occur at small scales of time and space, the ecological linkage is evidently propagated to multiyear changes in regional ocean areas (Li et al., 2006). As such, with further research, it may be possible to deduce the spatial distribution of various microbial groups on the basis of phytoplankton chlorophyll mapped by remote sensing in conjunction with local ecological considerations.

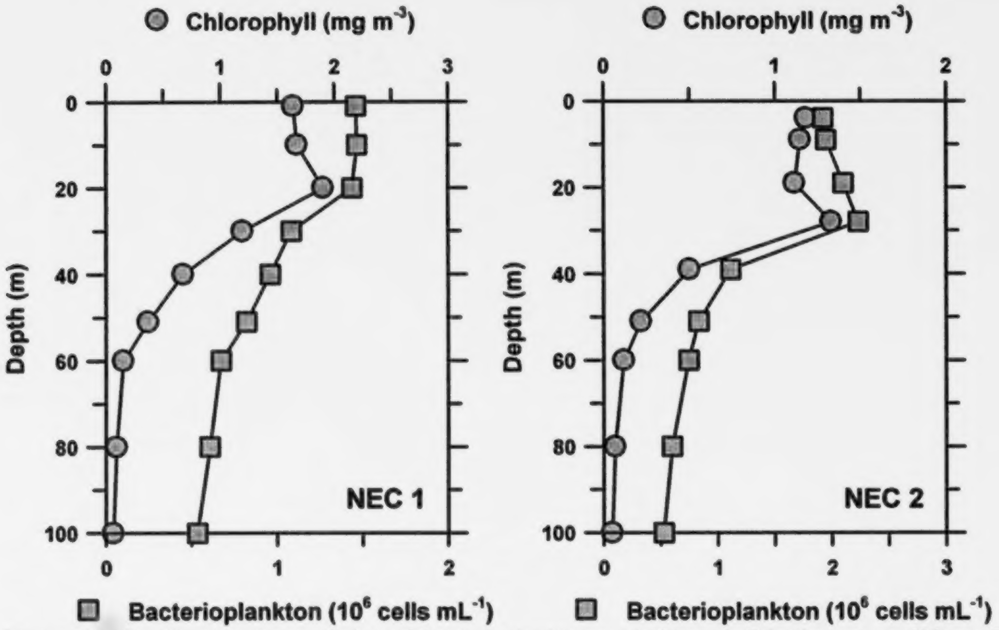


Figure 20. *Depth-related covariation of bacterioplankton and chlorophyll in the upper 100 m of the water column at 2 hydrographic stations in the Northeast Channel (NEC) of the Georges Bank moratorium area in June 2005 (Li et al., 2009).*

7.2 PHYTOPLANKTON

Phytoplankton includes bacteria, unicellular algae, and protists that perform oxygen-evolving photosynthesis. Despite tremendous phylogenetic diversity, all phytoplankton share the common feature of possessing chlorophyll *a* (or its divinyl derivative) as the primary light-harvesting pigment. As such, from an operational standpoint, the quantity of phytoplankton in the sea is most often measured as the concentration of chlorophyll *a*. The cytoplasm of some planktonic ciliates contains either modified algal endosymbionts or isolated plastids. This chimaeric microzooplankton performs photosynthesis, some in an obligate fashion comparable to algae and others in a facultative fashion as mixotrophs (i.e. capable of mixed modes of nutrition). There is great interest in the abundance and distribution of phytoplankton, as they play a vital role in aquatic ecosystem dynamics. Phytoplankton is the base of the marine food web and the primary source of nutrition for the animal component of plankton known as zooplankton (DFO, 2009a).

Townsend et al. (2006) is the most authoritative review of phytoplankton dynamics on Georges Bank. It describes the annual cycle of new and recycled production as an outcome of surface circulation, upwelling nutrient injections, tidal-pumping from nutrient-rich deep slope water, and microbial nitrification. Average annual phytoplankton production levels on Georges Bank are estimated to be 379 gC m^{-2} y^{-1} or 4270 t km^{-2} (Cohen and Grosslein, 1987; Gaichas et al., 2009). The yearly production cycle is highly variable, with the highest phytoplankton concentrations occurring during late winter or early spring, with lower concentrations occurring during summer. Seasonal differences in primary production are mainly related to variations in nutrient supply (e.g. nitrate, phosphate, and silicate) and light. On Georges Bank, planktonic ciliates that photosynthesize can contribute from 1-7% of the total fixed carbon. In the size class of microplankton, to which they belong, the ciliates can contribute from 14-90% of the fixed carbon (Stoecker et al., 1989).

High phytoplankton concentrations are observed following the formation of the seasonal thermal stratification during the winter-spring transition period, at a time when nutrient concentrations are high throughout the water column. Strong winter mixing and tidal influences contribute to the upwelling of deep, nutrient rich water, while seasonal heating of surface waters results in the development of strong upper stratification around the Bank. The nutrients and heat provide ideal growing conditions for phytoplankton, and a bloom will typically occur. The bloom ends once nutrients are depleted in surface waters, but may be further shortened by weather events, self-shading, and zooplankton grazing pressure (Breeze et al., 2002; Ji et al., 2008). Primary production is lowest in the stratified deeper water surrounding Georges Bank, especially in the summer, as nutrients become exhausted and are not replenished. These patterns are reflected in data collected from Georges Bank in the 1980s, as part of the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP). The data provided detailed spatial and temporal distributions of phytoplankton biomass and productivity (O'Reilly and Busch, 1984; O'Reilly et al., 1987). A secondary, less pronounced bloom is evident during destratification of the water column in the fall (i.e. typically October).

The phytoplankton community of Georges Bank is dominated by diatoms during the spring, late autumn, and winter and flagellates increase in importance during the summer and post-bloom (DFO, 2006a). Recent coupled ecosystem-circulation models have confirmed earlier field observations (e.g. Horne et al., 1989; Bisagni, 2003) that both local (i.e. biological) and external (i.e. physical) processes determine the seasonal nutrient supply and primary productivity of Georges Bank (Hu et al., 2008; Ji et al., 2008). In summer, internal nitrogen regeneration is the major nitrogen source for primary production on the central Bank, while mixing processes (e.g. tidal pumping and advection) fuel production on the flanks and bank-wide during other seasons. These models have also suggested that changes in the deep source waters, modulated by remote forcing (e.g. NAO, changes in Arctic outflow), influence nutrient fluxes to the Bank and its productivity.

Chlorophyll concentration generally ranges from 1-5 mg m^{-3} on Georges Bank, with the annual maximum typically occurring in late March (Page et al., 2001; Thomas et al., 2003; Frank et al., 2006). Satellite (SeaWiFS) measurements of chlorophyll *a* concentration are available at 4 km spatial resolution and 1 week time resolution throughout the Gulf of Maine over an 11 year period (1997-2007), and the data suggests there is no significant multiyear trend (Figure 21). A physiographic partition of this large area into 14 distinct regions allows an analysis of phytoplankton climatology and multiyear change on Georges Bank to be assessed in relation to neighbouring waters (Wolff and Incze, 2009).

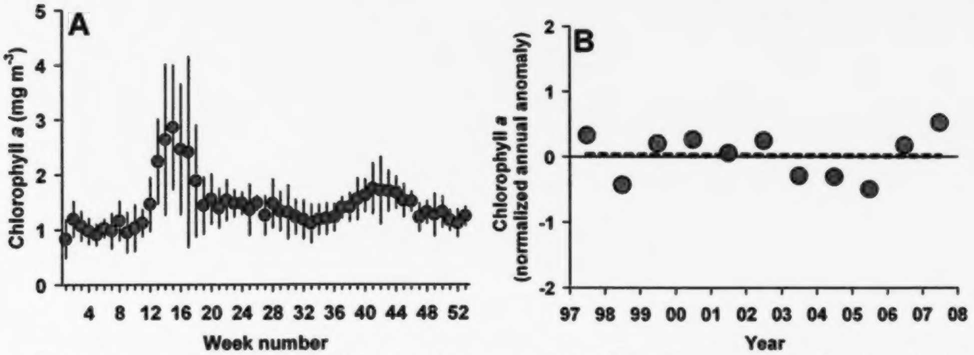


Figure 21. *Georges Bank phytoplankton: (A) annual cycle showing mean and standard deviation of weekly chlorophyll a concentration from 11 years of SeaWiFS observations; and (B) time series of normalized annual cholorphyll a anomaly indicating no significant multiyear trend (Li et al., 2009).*

Annual cycles of chlorophyll *a* show different amplitudes and timings across the 14 regions, although spring and fall phytoplankton blooms are common features almost everywhere. One exception is the Bay of Fundy, where high concentrations of suspended non-phytoplankton material may contaminate the presumed signal from chlorophyll *a*. In a ranked sequence of annual maximum chlorophyll, Georges Bank occupies a middle position between high concentrations of coastal shelf regions and low concentrations of shelf Basins (i.e. Georges, Wilkinson, Jordan) and the central Gulf of Maine (Figure 22A). The principal source of nutrients to the Gulf of Maine is the deep, nutrient-rich continental slope waters.

Steele at al. (2007) have suggested that the source of these deep, nutrient-rich waters has played a significant role in the overall productivity of Georges Bank, from plankton to fish, over the past several decades. In recent years, for example, there has been a greater contribution of colder and fresher deep waters originating upstream (i.e. Scotian Shelf and off-shelf LSW) linked to Arctic ice melt. As a result, there is now a lower residual concentration of nitrate (i.e. nitrate minus silicate) in the Gulf of Maine that may alter biomass, productivity, and community composition of phytoplankton (Townsend et al., 2009). An analysis of multiyear chlorophyll change in the 14 physiographic regions of the Gulf indicates that phytoplankton appear to be increasing in the shallow coastal shelf regions but decreasing over deep waters. Georges Bank is a region pivoted between positive and negative change (Figure 22B).

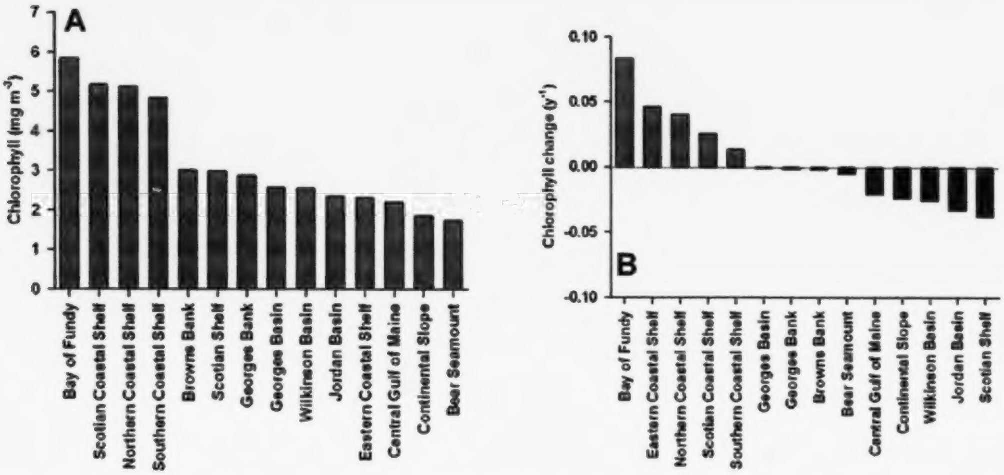


Figure 22. *Gulf of Maine Area phytoplankton physiographic regions: (A) maximum annual chlorophyll concentration per region; and (B) multiyear rate of chlorophyll change calculated from the linear regression of normalized annual anomaly time series data (Li et al., 2009).*

7.3 ZOOPLANKTON

Zooplankton includes animals that are unable to maintain their horizontal spatial distribution against current flow. Zooplankton range in size from 20 µm to more than 2 m in diameter. One commonly used size classification scheme divides zooplankton into: microzooplankton (20-200 µm), which includes ciliates, tintinnids, and the eggs and larvae of larger taxa; mesozooplankton (200 µm-20 mm), which include copepods, larvaceans, pelagic molluscs (pteropods and heteropods), and larvae of benthic organisms; macrozooplankton (2-20 cm), which include krill (euphausiids), arrow worms (chaetognaths), and amphipods; and megazooplankton (20 cm-2 m), which include larger, gelatinous taxa (Sieburth et al., 1978). Many zooplankton species consume phytoplankton and repackage the energy fixed by primary producers in larger-sized particles that can be consumed by higher trophic level organisms, such as fish, seabirds, and marine mammals.

Zooplankton have a diverse range of life history characteristics that mediate their response to environmental variability and influence their spatial distribution, seasonal timing, and interannual variability. For example, different groups may consume phytoplankton, zooplankton, detritus, or some combination; they have different physiological tolerances to environmental variables such as temperature and salinity, as well as may have different 'refuge' traits such as dormancy or vertical migration. Different gear types are required to quantitatively sample zooplankton of different sizes and zooplankton sampling efforts on Georges Bank have been dominated by gear equipped with mesh sizes that capture mesozooplankton most efficiently. For this reason, variability patterns are better characterized for this group than for the smaller and larger size classes that may occupy the Bank.

The mesozooplankton community on Georges Bank is dominated by relatively few species. Six copepod species make up approximately 80% of the abundance of the mesozooplankton community at any given time of year (Davis, 1987). These species include: *Calanus finmarchicus* and *Pseudocalanus* sp. (winter/spring dominants); *Paracalanus parvus*, *Centropages typicus,* and *Centropages hamatus* (summer/ fall dominants); and *Oithona similis* (abundant year-round) (Davis, 1987). Twenty three taxa constitute approximately 95% of the total mesozooplankton abundance on Georges Bank (Kane, 2007). The Georges Bank zooplankton community has a strong seasonal cycle in terms of both abundance and biomass. Total zooplankton abundance is highest in May-June, reaching average concentrations on the order of 10^3 individuals m^{-3} (Kane, 2007). Zooplankton displacement volume, a proxy for biomass, is also highest in May-June and lowest in December-January for all regions of the Bank (Sherman et al., 1987). While displacement volumes follow the same seasonal cycle in all sub-regions of the Bank, they are lower on the flanks of the Bank compared to inside the 100 m depth contour.

Calanus finmarchicus is the biomass dominant zooplankton species on the Bank and in much of the Gulf of Maine. Its life cycle includes a period of dormancy (i.e. suppressed development) in the late summer and fall in deep water, such as Gulf of Maine basins. Prior to dormancy, the species builds up a large oil sac containing storage lipids, fulfilling a role in the ecosystem as a large, energy rich species that is an important food source for planktivorous fish such as herring and for Northern right whales. Larvae of *C. finmarchicus* are prey for larval cod and herring on the Northeast Peak of Georges Bank, as are the larvae of another abundant copepod *Pseudocalanus* sp. (Buckley and Durbin, 2006). The Gulf of Maine is the primary source of *C. finmarchicus* to the Bank in late winter, when they emerge from dormancy, migrate to surface waters, and are transported onto the northern Flank and Northeast Peak of the Bank (Bigelow, 1926; Lynch et al., 1998).

As the *C. finmarchicus* population increases on the Bank from January to April, the impact of the gyre circulation on population development is evident. The Bank is in high abundance of younger stages (nauplii) on the Northeast Peak proximal to where mature adults arrived on the Bank and spawned, as well as in high abundance of older stages (copepodids) downstream of the Northeast Peak on the Southern Flank where they were transported as they grew and developed (Durbin and Casas, 2006). A similar interaction between circulation and population development has been observed in *Pseudocalanus* spp. on Georges Bank (Davis, 1984). Although phytoplankton production on Georges Bank is high throughout the year, food limitation on growth and reproduction has been observed in *C. finmarchicus* on the Southern Flank in April to May in certain years (Wiebe et al., 2002).

The abundance of invertebrate predators of zooplankton, including chaetognaths, suspended hydroids, medusae, euphausiids, and amphipods, is highest on the crest of the Bank (Sullivan and Meise, 1996). For *C. finmarchicus*, off-bank advection results in the greatest losses from the Bank in January, while predation on eggs by older-stage *C. finmarchicus* and planktonic hydroids is the dominant source of mortality in the late winter and spring (Ohman et al., 2008). Although a substantial portion of the zooplankton produced on the Bank is transported off the bank, particularly toward the southwest onto Nantucket Shoal and toward the Mid-Atlantic Bight, modeling studies have demonstrated that taxa developing in the Georges Bank gyre can be retained on the Bank. For example, some of the *C. finmarchicus* that develop on the Bank are retained in the gyre and could contribute to their source region in the western Gulf of Maine (Miller et al., 1998). In addition, a portion of the sea scallop larvae spawned on Georges Bank scallop beds are retained on the Bank and can re-seed either their source bed or other Georges Bank scallop beds (Gilbert et al., 2010).

In contrast to species like *C. finmarchicus*, *Pseudocalanus* spp., and *Metridia* spp., which have off-bank sources and are abundant in the stratified regions of the Bank, several species including *Centropages typicus*, *Centropages hamatus*, and *Temora longicornis* have on-bank sources and their populations are centered on the retentive crest of Georges Bank, as well as in the tidal mixing front (Durbin and Casas, 2006). These species are most abundant in the summer and fall. In addition, zooplankton can be transported onto Georges Bank from intrusions of WSW and WCRs that bring warm-water oceanic zooplankton species onto the Bank (Colton et al., 1962; Brown et al., 2005). Inputs of Scotian Shelf Water crossing the Northeast Channel onto the Northeast Peak can transport cold-water shelf species, similar to the Bank community, onto Georges Bank (Wishner et al., 2003).

Zooplankton biomass on Georges Bank can vary considerably from year to year, based on observations since 1971 (Wiebe et al., 2002). Winter, early spring, and spring zooplankton biomass on Georges Bank have been at intermediate levels during the past several years. There is some evidence that zooplankton abundance has been increasing in the winter (January-February), but decreasing in the spring (March-April) (NOAA, 2008). Mean zooplankton biomass on the Bank in February 2009 was the highest concentration observed in DFO surveys since 1999 at 70 g per m^3 (average of approximately 20 g per m^3) (Harrison et al., 2009). The abundance of *C. finmarchicus* also varies from year to year, and the interannual variability patterns of this species are similar in the Gulf of Maine and on Georges Bank (Figure 23).

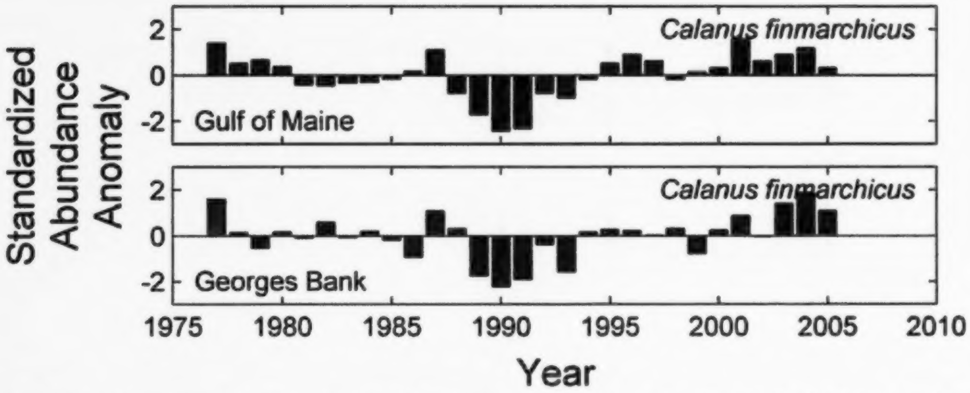


Figure 23. *Mean annual abundance of Calanus finmarchicus in the Gulf of Maine and on Georges Bank, based on NEFSC plankton monitoring sampling using bongo gear (pers comm. M. Fogarty – NEFSC National Oceanic and Atmospheric Administration, 2009).*

On Georges Bank, *C. finmarchicus* abundance was lower than average from 1989-1993. After a period of approximately average abundance in the mid-1990s to early-2000s, *C. finmarchicus* abundance increased sharply in 2003, reaching a time-series maximum in 2004 (Kane, 2007). Abundance anomalies (i.e. annual average abundance with the seasonal abundance cycle removed) of *C. finmarchicus*, a cold-water, winter-spring dominant species, were negatively correlated with temperature in the time series, while abundance anomalies of *Centropages typicus* and *Centropages hamatus*, warm-water, summer-fall species, were positively correlated with temperature (Kane, 2007). The abundance trends of several species of copepods on Georges Bank are correlated with one another from year to year. The abundance of *Centropages typicus*, *Metridia lucens*, *Temora longicornis*, and *Oithona* spp. all increased to above average or average values from 1989-2001 (Figure 24) (Kane, 2007). The abundance of *C. typicus*, *M. lucens*, and *T. longicornis* declined beginning in 2002, while the abundance of *Oithona* sp. continued to be abundant (Kane, 2007). Similar coherent interannual variability patterns have also been observed among small copepod species in the Gulf of Maine (Pershing et al., 2005; Greene and Pershing, 2007).

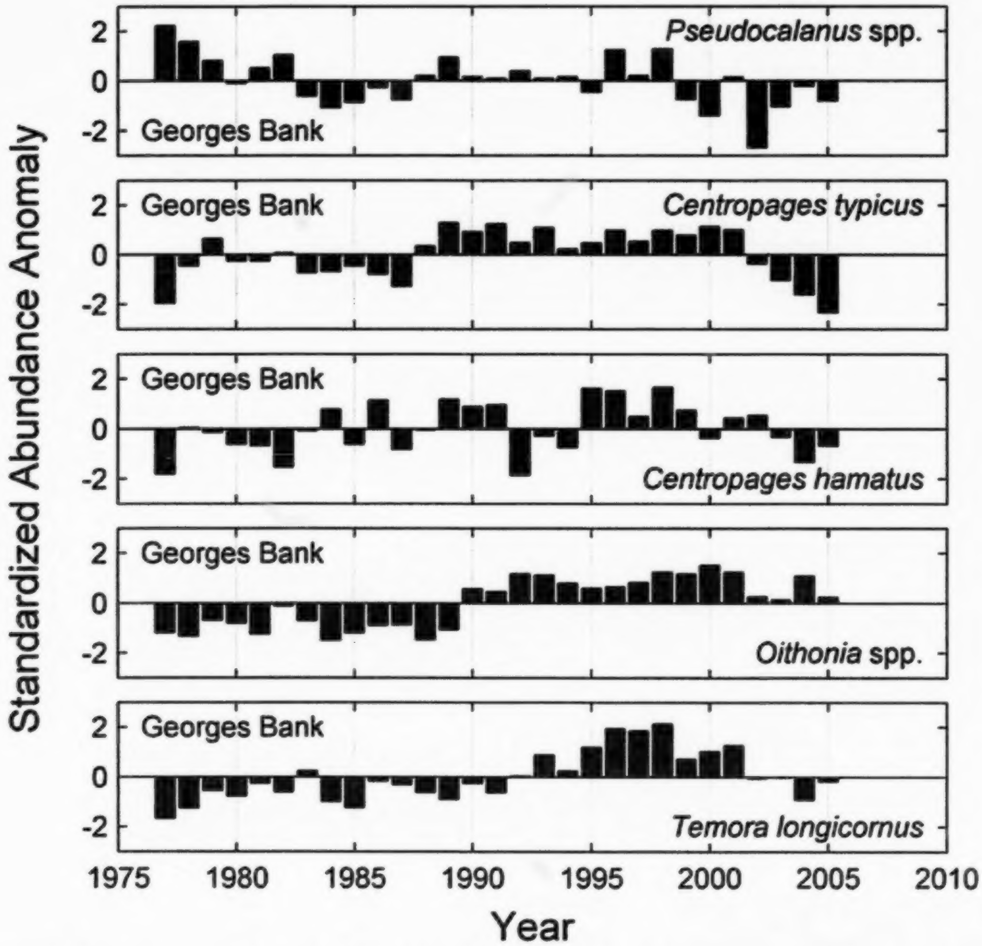


Figure 24. *Mean annual abundance of Pseudocalanus sp., Centropages typicus, C. hamatus, Oithona spp., and Temora longicornis in the Gulf of Maine and on Georges Bank, based on NEFSC plankton monitoring sampling using bongo gear (pers comm. M. Fogarty – NEFSC National Oceanic and Atmospheric Administration, 2009).*

The Georges Bank zooplankton community shift of the 1990s coincided with a decrease in salinity in the Gulf of Maine and on Georges Bank caused by increased inflow from the Scotian Shelf (Kane, 2007). Survival of these species through autumn may be enhanced when low salinity waters move into the eastern Gulf of Maine from the Scotian

Shelf and stabilize the water column. This would allow phytoplankton to grow during the autumn or winter when the water column is normally well mixed (Durbin et al., 2003; Pershing et al., 2005; Kane, 2007). This hypothesis is supported by observation of much higher abundances of *C. typicus*, *Oithona* sp., *Pseudocalanus* sp., *M. lucen*, and late-stage *C. finmarchicus* in the central Gulf of Maine in the winter of 1999, which was a year when colder, low-salinity water was present in the Gulf and a winter bloom occurred. This is in contrast to the winter of 2000, when conditions were more typical, exhibiting higher surface salinity, no winter bloom, and low copepod abundance (Durbin et al., 2003).

Alternatively, advective input could also have contributed to changes in the zooplankton community in the 1990s (Kane, 2007). The species that increased in abundance in the 1990s have diverse life histories and phenologies and occupy a range of ecological niches (Pershing et al., 2005). As such, zooplankton community shifts, such as those observed on Georges Bank in the past several decades, are likely to influence the pathways, magnitude, and seasonal timing of energy transfer throughout the Georges Bank ecosystem.

8.0 BENTHIC INVERTEBRATES

A number of studies have attempted to document and describe the benthic fauna, including worms, clams, sea stars, sea urchins, crustceans, sea cucumbers, tunicates, sponges, hydroids, and corals of Georges Bank, often in relation to sediment type and some description of seasonal trends (Wigley, 1961; Maurer and Leathem, 1980; Dickinson and Wigley, 1981; Maurer and Leathem, 1981a,b; Maurer, 1983; Michael et al., 1983; Maciolek and Grassle, 1987; Theroux and Grosslain, 1987). A study by Cohen and Grosslein (1987) estimated that the production of macrobenthos on Georges Bank was similar to the Gulf of Maine and slightly higher than the Scotian Shelf. An analyis of data collected from the mouth of the Bay of Fundy to southwestern New England in the 1950s and 1960s indicated high densities of 1961 specimens m^{-2} and biomass of 233 g m^{-2} of macrobenthos on Georges Bank (similar to the southern New England Shelf and higher than the Gulf of Maine), but lower densities of 300 specimens m^{-2} and 21 g m^{-2} on Georges Slope (similar to the southern New England slope) (Theroux and Wigley, 1998).

In a study of benthic organisms retained in a 10 mm mesh sieve on the Northeast Peak of Georges Bank, 140 taxa were identified with 76% of which were epibenthic (Thouzeau et al., 1991). The epibenthic species collected included: polychaetes (23%), gastropods (19%), crustaceans (14%), echinoderms (12%), poriferans (7%), acidians (7%), and bivalves (7%). Infauna species were mostly bivalves (58%) and polycheates (24%). Bivalves dominated in density (55%) and biomass (86%), with three species (i.e. scallops, surf clams, and ocean quahogs – each with discrete distributions) representing 71% of total biomass. This was noted to reflect the leading role of filter-feeders on the Northeast Peak. Bivalve predators, such as decapods, boring gastropods, and echinoderms, exhibited density dependent relationships with their prey. Overall, densities generally declined with depth, with sediment type considered to be the major factor influencing the distribution of benthic organisms. The highest diversity of organisms was found on biogenic habitat, containing polycheate tube structures. Epibenthic sessile taxa (i.e. sea squirts, sponges, sea anemones and coral) demonstrated low abundance and biomass, though they were regularly observed.

A more recent study by Link (2004) analyzed the U.S. groundfish stomach database from the Gulf of Maine area to determine whether benthic species had declined in the period since the intensive sampling of the 1950s and 1960s, as well as to determine whether groundfish diets might be used to detect changes in benthic communities rather than by direct sampling. The study indicated that most species examined had not declined over the previous 30 years, with two groups (i.e. sea stars and mantis shrimp) exhibiting a slight increase in relative abundance (Link, 2004). More recently, direct investigations of benthic communities (i.e. megafauna greater than 5 mm in size) on Georges Bank have been conducted, in order to investigate the impacts of human disturbance (Collie et al., 1997; Collie et al., 2000; Collie et al., 2004; Link et al., 2004; Collie et al., 2009). The studies indicate that fragile species, such as a tube-building polycheate (*Thelepus cincinnatus*), brittlestar (*Ophiopholis aculeata*), toad crab (*Hyas coarctatus*), and shrimp (*Dichelopandalus leptocerus*), were found in higher abundance at less disturbed sites (Sites 13 and 17 in Figure 25). In contrast, bivalves and echinoderms tended to dominate at a more disturbed site (Site 20 in Figure 25).

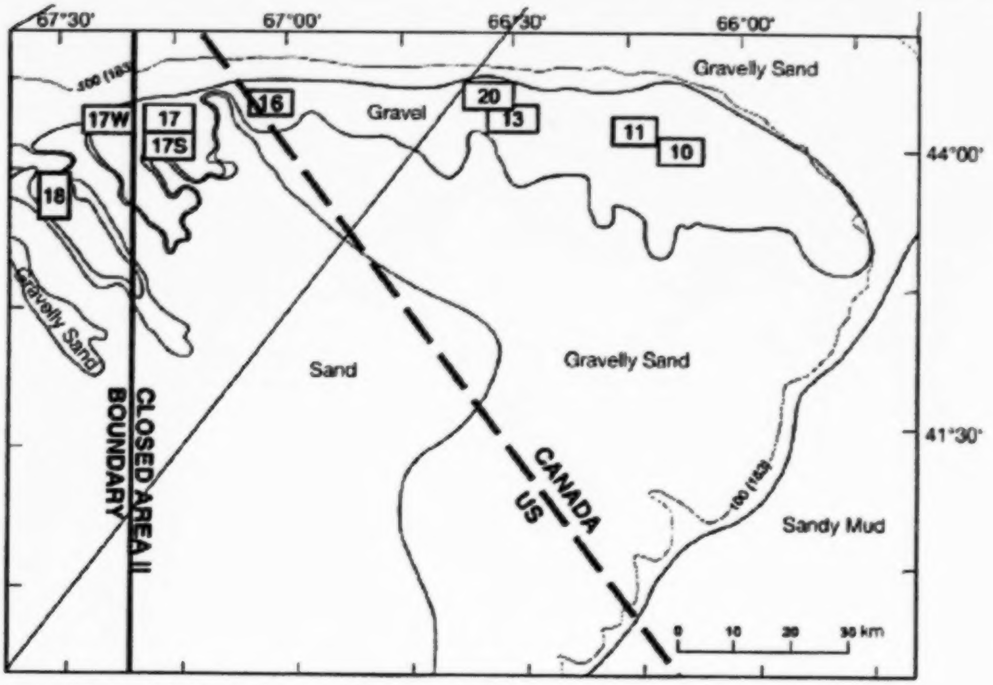


Figure 25. Benthic locations sampled from 1994-2000.

The studies also demonstrate that changes in community structure occurred after a fishery closure in 1995 at a gravel site (Site 17 in Figure 25), which transitioned from bare gravel in 1994, to biogenic cover grazed by nudibraches by 1996, to colonization by sponges, hydrozoans, crabs, and small scallops by 1997 and, last, to increased sponge cover with small colonies of Filograna by 1999. The number of species found at Site 17 increased from 24 in 1994 to 54 by 2000. Biomass and production were also found to increase at the site. Select benthic species are summarized in the Appendix.

8.1 AHERMATYPIC CORALS

Distribution, Habitat, Abundance, and Predator and Prey

Ahermatypic corals (hereafter referred to as corals) do not contain zooxanthellae (algae) and, as such, are not restricted to shallow depths where high levels of light penetrate. They can exist, however, at almost any depth from the shallow intertidal zone to the deep abyss. Compared with similar shallow-water corals, ahermatypic corals are poorly studied in part due to their inaccessibility, since most species are found at depths greater than 200 m of the continental slopes, canyons, or seamounts.

Population Structure Relative to Moratorium Area

Since Gordon and Kenchington (2007) reviewed the distribution of corals in the DFO Maritimes Region, data from scientific research missions targeting corals have significantly increased the knowledge of the distribution of the taxa (Cogswell et al., 2009). Thirty-one coral taxa are now known to occur in the Georges Bank moratorium area (Table 2). These are primarily Octocorallia (soft corals), although some

Hexacorallia (stony corals) have also been identified. Not all of these taxa are mutually exclusive due to difficulties in identification of specimens from photographs alone, although, 17 specimens have been identified down to the species level and another five down to genera level. At least 22 species or coral have been identified in the moratorium area, indicating a diverse coral fauna in the region.

Table 2. *Coral taxa known to reside in the Georges Bank moratorium area.*

Coral Taxon	Type	Common Name
Anthomastus agassizii	Alcyonacean	Mushroom coral
Anthomastus grandiflorus	Alcyonacean	Mushroom coral
Anthomastus spp.	Alcyonacean	Mushroom coral
Capnella florida	Alcyonacean	Broccoli coral
Nephtheidae	Alcyonacean	Soft coral
Acanella arbuscula	Gorgonian	Maple trees
Acanthogorgia armata	Gorgonian	
Anthothela grandiflora	Gorgonian	
Gorgonacea	Gorgonian	
Keratoisis ornata	Gorgonian	Bamboo coral
Paragorgia arborea	Gorgonian	Bubblegum coral
Paragorgia sp.	Gorgonian	Bubblegum coral
Paramuricea borealis	Gorgonian	
Paramuricea grandis	Gorgonian	
Paramuricea placomus	Gorgonian	
Paramuricea spp.	Gorgonian	
Primnoa resedaeformis	Gorgonian	Sea corn
Primnoa sp.	Gorgonian	Sea corn
Radicipes spp.	Gorgonian	
Anthoptilum murrayi	Pennatulacean	Sea pen
Balticina finmarchica	Pennatulacean	Sea pen
Halipteris spp.	Pennatulacean	Sea pen
Kophobelemnon sp.	Pennatulacean	Sea pen
Pennatula spp.	Pennatulacean	Sea pen
Octocorallia		
Desmophyllum spp.	Scleractinian	
Flabellum angulare	Scleractinian	Cup coral
Flabellum spp.	Scleractinian	Cup coral
Lophelia pertusa	Scleractinian	Spider hazards
Stephanocyathus diadema	Scleractinian	
Anthozoa		

In June 2002, the Northeast Channel Coral Conservation Area (NEC CCA) was established by DFO (Mortensen and Buhl-Mortensen, 2004). The NEC CCA lies inside the Georges Bank moratorium area (Figure 26). The conservation area was primarily selected on the basis of its high density of large branching gorgonian corals, such as *Paragorgia arborea* and *Primnoa resedaeformis* compared with the surrounding area (Mortensen and Buhl-Mortensen, 2004) (Figure 27). The NEC CCA was also established because of visual evidence of disturbance, such as broken live coral, tilted corals, and skeletal fragments, indicating that the area was vulnerable to bottom fishing damage. The closest, high density aggregations in Canadian waters are found to the east of the Gully Marine Protected Area (MPA). Large gorgonian corals are not found in the Bay of

Fundy, in high concentrations on Brown's Bank, or elsewhere on the western Scotian Shelf.

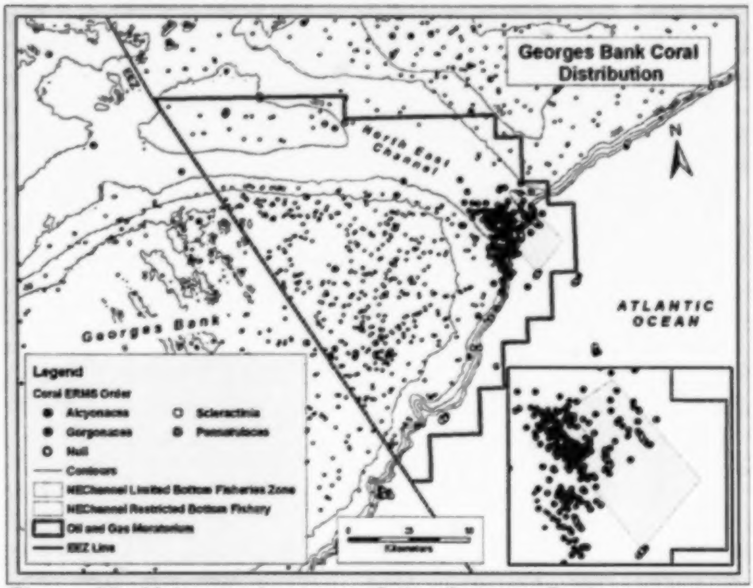

Georges Bank Coral Distribution
North East Channel
N
ATLANTIC OCEAN
Georges Bank
Legend
Coral ERMS Order
Alcyonacea
Gorgonacea
Null
Scleractinia
Pennatulacea
Contours
NEChannel Limited Bottom Fisheries Zone
NEChannel Restricted Bottom Fishery
Oil and Gas Moratorium
EEZ Line
Kilometers

Figure 26. Major coral groups of the Georges Bank moratorium area. Boundaries of the Northeast Channel Coral Conservation Area are more clearly defined in the inset. Data on the graphic are from multiple sources (Cogswell et al., 2009).

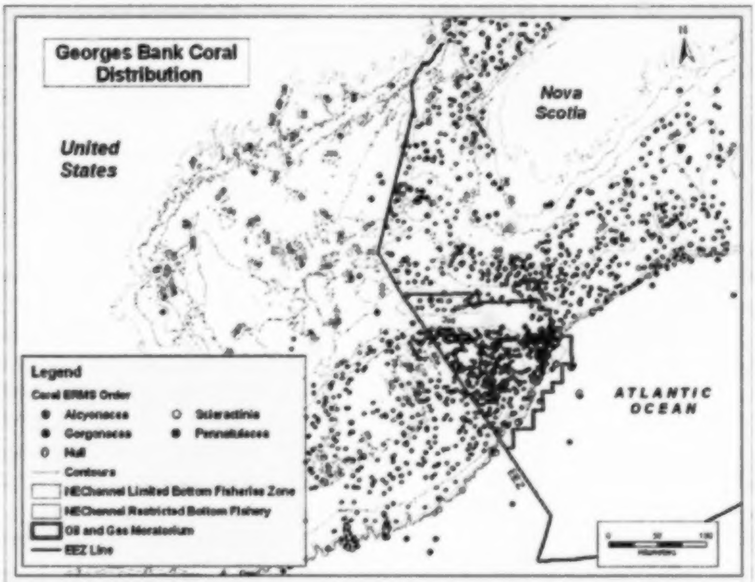

Georges Bank Coral Distribution
N
Nova Scotia
United States
ATLANTIC OCEAN
Legend
Coral ERMS Order
Alcyonacea
Gorgonacea
Null
Scleractinia
Pennatulacea
Contours
NEChannel Limited Bottom Fisheries Zone
NEChannel Restricted Bottom Fishery
Oil and Gas Moratorium
EEZ Line
Kilometers

Figure 27. Major coral groups of the Georges Bank moratorium area and surrounding regions. Data on the graphic are from multiple sources (Cogswell et al., 2009)

Life History, Location, and Timing

Corals form important structural habitats that contribute to vertical relief and increase the availability of microhabitats (Tissot et al., 2006). Coral habitats provide feeding opportunities for aggregating species, hiding places from predators, nursery areas for juveniles, fish spawning aggregation sites, and attachment substrates for fish egg cases and sedentary invertebrates (Fosså et al., 2002; Reed, 2002; Etnoyer and Morgan, 2003). For example, in the Northeast Channel, redfish were almost four times more common in video sequences in the presence of corals than in the absence of corals (Metaxas and Davis, 2005; Mortensen et al., 2006).

Known Vulnerabilities

Most corals are highly vulnerable to human activities, in particular, bottom contacting activities such as fishing. Corals are filter feeders and, as such, are also vulnerable to intake of organic and inorganic contaminants in the water column and in bottom sediments. The various impacts of oil pollution and dispersants are reviewed by Happkla et al. (2007).

Status Designation

There is a strong international conservation movement calling for the protection of corals using closed areas and bans on certain fishing gear types. The NEC CCA is 424 km^2 in area and consists of two fishing management zones (Figure 26). A restricted bottom fishing zone comprises approximately 90% of the CCA, which is closed to all bottom fishing gear used for groundfish or invertebrate fisheries (e.g. longline, otter trawl, gillnet, and trap). The remaining 10% of the CCA is open to limited authorized fishing. At present, the limited fishing area is open only to longline fishing gear for groundfish in the presence of an at-sea observer, but remains closed to all other bottom fishing gear.

8.2 SEA SCALLOP

Distribution, Habitat, Abundance, and Predator and Prey

Sea scallop, *Placopecten magellanicus*, occupies a geographic range in the northwest Atlantic Ocean that extends from Labrador, Canada, to Cape Hatteras, U.S. Georges Bank is the largest and most productive scallop area in this range (Brand, 2006). It supports an abundance of sea scallops due to its ideal benthic habitat that results from the water temperature, food and oxygen availability, substrate type, and other oceanographic conditions that contribute to spawning and settlement success. Sea scallops prefer sandy, gravel bottoms on the Bank and occur at shallow water depths of 35-120 m (DFO, 2008a). It is worth noting that dense aggregations of juveniles are often found in areas where the density of adults has been low and, as such, the distribution of juveniles does not necessarily match the distribution of adults at any one time (Figure 28).

Sea scallops are filter-feeders and their diet consists mainly of phytoplankton. The growth rate of scallops varies from one area to another and is likely influenced by season, depth, food availability, and water temperature. Georges Bank, as previously described, exhibits unique environmental conditions that result in rapid movement of well mixed water rich in food and oxygen. The Bank is one of the world's most productive areas for the species and represents some of the fastest observed growth rates for sea scallop stocks (Bourne, 1964).

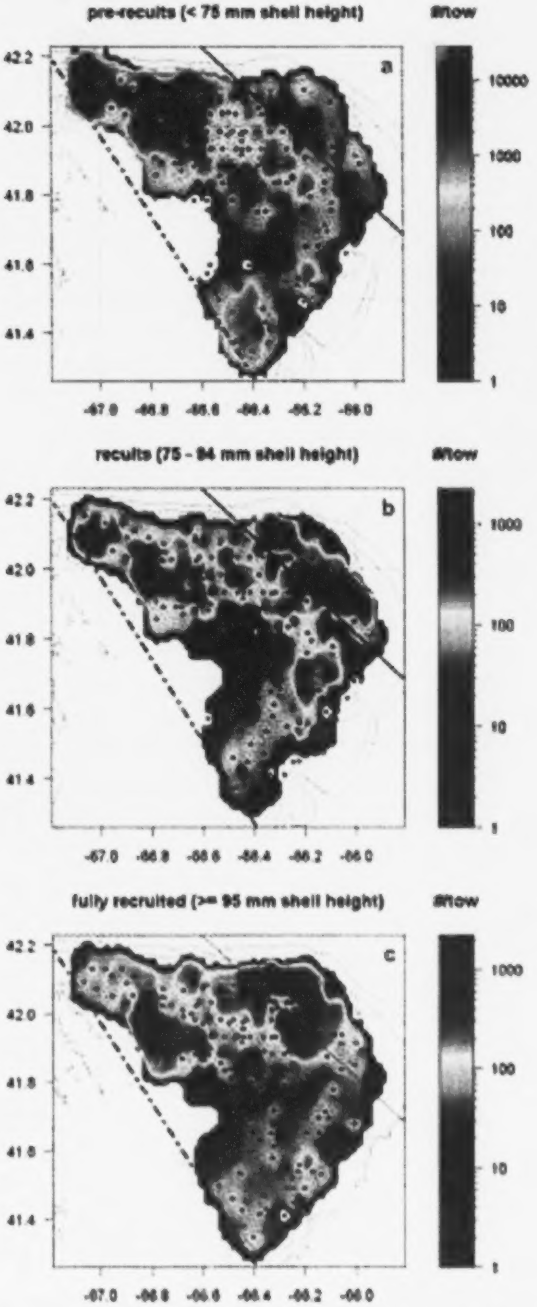

pre-recuits (< 75 mm shell height)
#/tow
a
42.2
42.0
41.8
41.6
41.4
-67.0
-66.8
-66.6
-66.4
-66.2
-66.0
10000
1000
100
10
1
recuits (75 - 94 mm shell height)
#/tow
b
1000
100
10
1
fully recruited (>= 95 mm shell height)
#/tow
c
1000
100
10
1

Figure 28. Distribution of sea scallop catches from the 2008 Georges Bank survey: (a) pre-recruits; (b) recruits; and (c) fully recruited (i.e. commercial sizes). Tow positions are represented by the black dots.

Population Structure Relative to Moratorium Area

Sea scallops on Georges Bank are generally found in three main aggregations: Northeast Peak, Great South Channel, and the southern edge of the Bank. The Northeast Peak aggregation supports an important fishery in eastern Canada. Sea scallops are sedentary once they have settled on the ocean bottom as spat. On the Northeast Peak, larval distribution has been shown to be positively related to water column stratification (Tremblay and Sinclair, 1990). Models that link larval biology and settlement numbers with the hydrodynamics and particle dynamics on Georges Bank indicate a significant exchange of larvae among the three main scallop aggregations (Tremblay et al., 1994; Tian et al., 2009). This, coupled with the presence of a partial gyre on Georges Bank that contributes to the retention of larvae on the Bank, supports the theory of a self-sustaining population of sea scallops on Georges Bank.

The Canadian portion of Georges Bank is managed using two zones. Zone 'a' is the traditional scallop fishing ground and the more productive area. It comprises the majority of the area of the Canadian side of Georges Bank. The abundance of Georges Bank scallop has been at or above the 27 year median since 1999. Biomass of fully recruited scallops reached the highest levels in the time series from 2000-2002 and it remained well above the long term median in 2008. An extremely large cohort of pre-recruits was observed in 2008, which is expected to recruit to the fishery in 2010-2011. Higher commercial biomass levels are expected at this time (Figure 29).

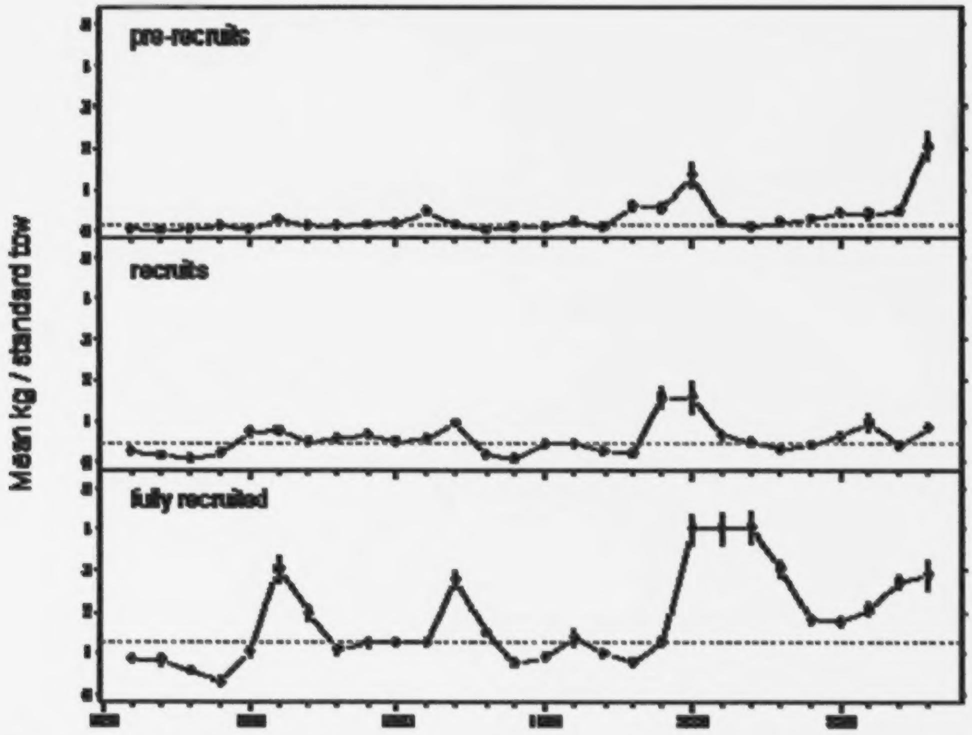


Figure 29. Sea scallop survey biomass indices for Georges Bank management Zone 'a' as the mean weight per standard tow (kg standard tow^{-1}) for pre-recruit, recruit, and fully recruited scallops. The dashed lines are the 27-year median value for each size class.

Life History, Location, and Timing

The predominant spawning period for sea scallops on Georges Bank occurs from late August to October, although a brief spring spawning period from May to June is observed during most years (DiBacco et al., 1995). The annual recruitment for the species is variable, even though adult females are highly productive and produce approximately 50 million eggs per year per individual. For the first 6-8 weeks, larvae remain in the water column where they grow in size. After six to eight weeks of planktonic life, larvae settle to the bottom at a size of about 300 μm.

Known Vulnerabilities

Scallops, as filter-feeders, are vulnerable to ingestion of contaminants and other particulate matter. Chronic contamination exposure to drilling wastes is believed to have strong sub-lethal effects on scallop growth and reproduction (Cranford et al., 1999). Exposure to drilling mud has the potential for up to 48 days of growth inhibition, although this is dependent on location and settling velocity of waste material (Cranford et al., 2003).

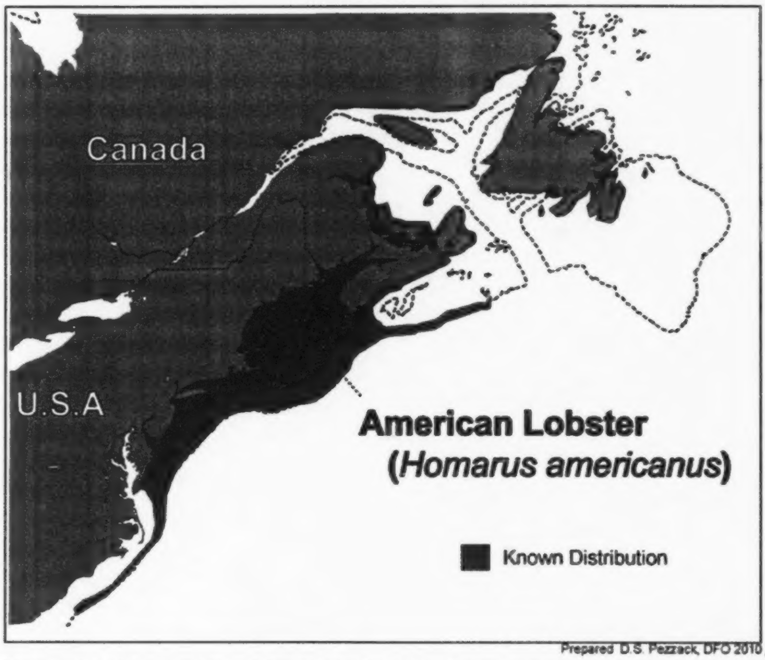
Status Designation

Georges Bank scallop is not listed pursuant to the *Species at Risk Act* (SARA) and has not been evaluated by the Committee on the Status for Endangered Wildlfe in Canada (COSEWIC).

8.3 LOBSTER

Distribution, Habitat, Abundance, and Predator and Prey

American lobster, *Homarus americanus*, are primarily found in coastal waters from southern Labrador, Canada, to Maryland, U.S., with highest abundance found in the coastal waters of the southern Gulf of St. Lawrence and Gulf of Maine (Figure 30). Lobsters also inhabit the continental shelf and upper continental slope of the northwest Atlantic Ocean from the Scotian Shelf, Canada to South Carolina, U.S. This includes the deep central basins of the Gulf of Maine. In the offshore, lobster densities are typically 10-100 times less than those of the more productive coastal water regions (Uzmann et al., 1977a; Cooper and Uzmann, 1980). The highest abundance of lobsters on Georges Bank is found in canyons along the Bank's outer slope and, to a lesser extent, along the northeast edge (Figure 31).


Canada
U.S.A
American Lobster
(Homarus americanus)
■ Known Distribution

Prepared D.S. Pezzack, DFO 2010

Figure 30. *Distribution of American lobster, Homarus americanus, in the Northwest Atlantic.*

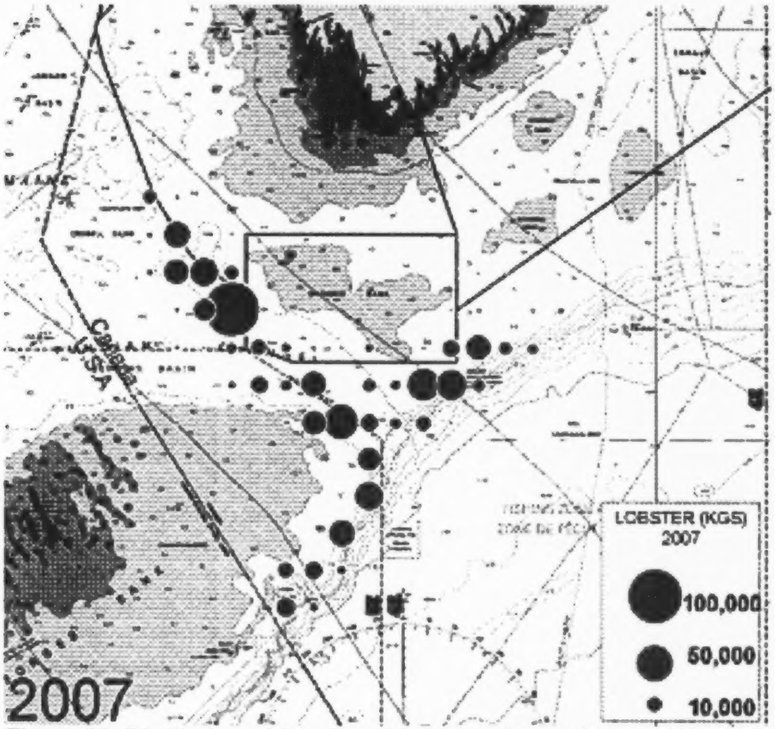

Canada
USA
LOBSTER (KGS)
2007
100,000
50,000
10,000
2007

Figure 31. *Distribution of American lobster landings in Lobster Fishing Aea 41 in 2007. Data is aggregrated by 10 minute grids.*

Lobster larvae are carnivorous, feeding primarily on copepods, decapod crustacean larvae, and fish eggs. Adult lobsters feed primarily on bottom dwelling invertebrates (e.g. crabs, polychaetes, mussels, periwinkles, sea urchins, brittle stars, and sea stars), as well as fishes and seaweeds (Carter and Steele, 1982, Elner and Campbell, 1987).

Canadian landings of lobster from Georges Bank have been relatively stable since 2000, with catch per unit effort (CPUE), both standardized and unstandardized, increasing through time (Pezzack et al., 2009) (Figure 32). The U.S. landings of the Georges Bank lobster fishery remained stable from 1981-2002 at an average of 1300 t. From 2003-2007, landings almost doubled, reaching a high of 2400 t in 2005, where it has since remained. The 2009 American assessment concluded that the Georges Bank stock has increased recently, with the current abundance and spawning stock biomass (Figure 33) being at record highs compared to the 26-year time series (ASMFC, 2009) (Figure 34). In contrast, exploitation is below the median value for the 22-year time series (ASMFC, 2009) (Figure 35).

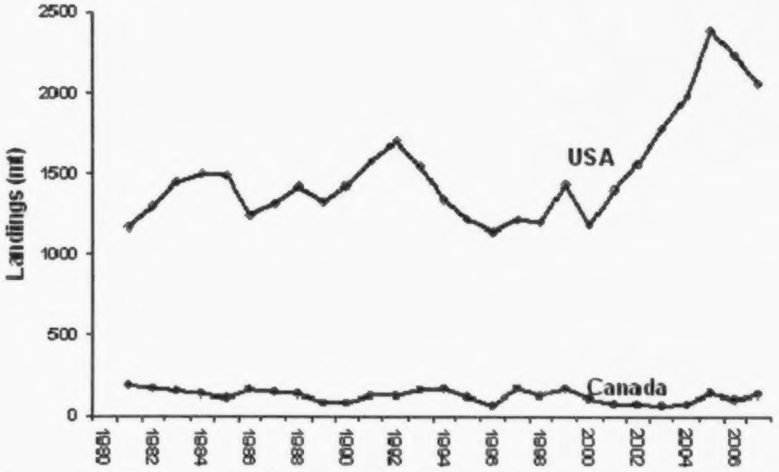


Figure 32. *Georges Bank lobster landings (metric tones, mt) from Canadian LFA 41 and American offshore lobster fisheries.*

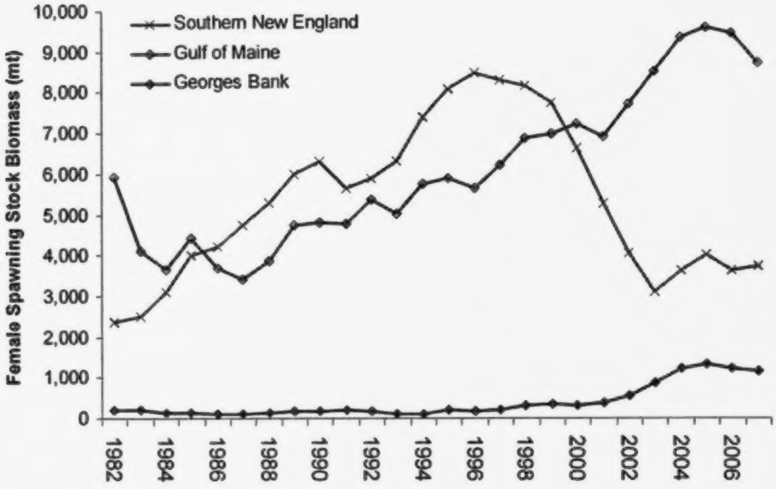


Figure 33. *Estimates of lobster spawning stock biomass (metric tonnes, mt) from the basecase model (ASMFC, 2009).*

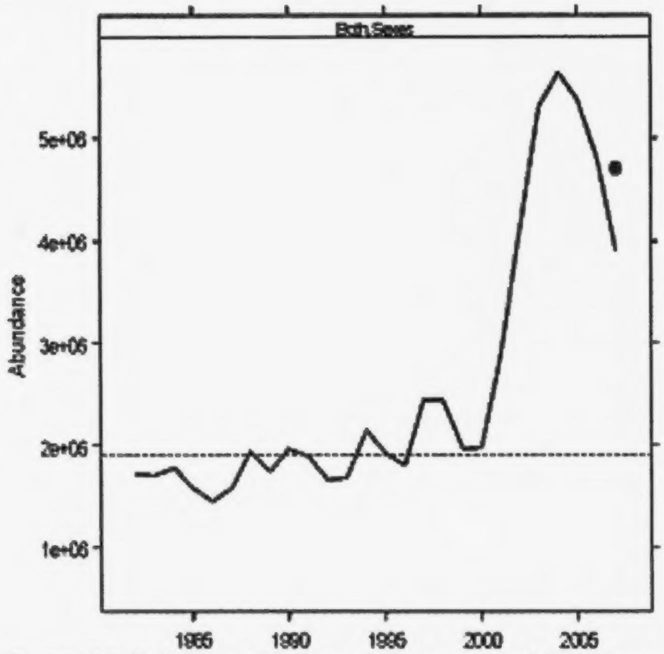


Figure 34. *Reference abundance with associated trend based reference point (median 1982-2003) and status measure (mean 2005-2007) from the basecase model for Georges Bank lobster.*

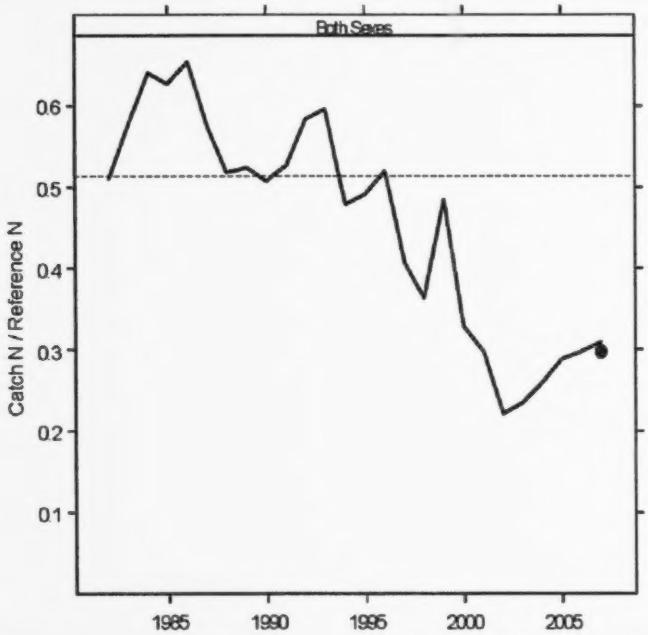


Figure 35. *Annual effective exploitation rate, with associated trend based reference point (median 1982-2003) and status measure (mean 2005-2007) from the base case model for Georges Bank (ASMFC, 2009).*

Population Structure Relative to Moratorium Area

In summer, lobsters in the Georges Bank region move from deeper waters surrounding the Bank (i.e. 300-700 m) to the shoal waters of the central plateau to moult and mate (Uzmann et al., 1977b; Pezzack and Duggan, 1987; Pezzack et al., 2009). The eggs are carried by the female for the next 10 months, after which they return to the shallow waters of the Bank and hatch the eggs the following summer. Migrations onto the Bank can range from a few kilometres up to 100 km in distance. The adult lobsters tend to remain in the vicinity of the Bank and mix little with other areas. This may result in distinct and unique populations. For example, genetic work using microsatellite markers has shown gene flow between lobsters from Georges Bank and Cape Cod, as well as the outer shelf south of the Great South Channel, but with barriers and low gene flow between Georges Bank lobsters and lobsters from coastal Maine and the Scotian Shelf (Kenchington et al., 2009).

It is not known what percentage of lobster larvae is retained by the partial gyre of Georges Bank, although pelagic lobster larvae have been observed on the northern edge of Georges Bank in July and August. This indicates some degree of off-bank movement (Harding et al., 1995; Harding et al., 2005). As such, a loss of some larvae off bank is expected, although the contribution of Georges Bank lobster to populations in the Gulf of Maine remains unclear.

Life History, Location, and Timing

The timing of summer migrations to mate and moult appears to be temperature dependent. The first hatching of lobster eggs on Georges Bank occurs in June and July (this precedes hatching on nearby Browns Bank and German Bank, which occurs in late July and early August). Newly-hatched larvae move to surface waters where they feed on a variety of planktonic species such as cladocerans and copepods, as they develop through four moult stages. After approximately a month in the water column, lobster larvae settle to the seabed and continue with a fifth moult stage. In winter, lobsters migrate back to deeper waters, although immature lobsters may remain on the shallow central plateau where they reside in sheltered, rocky areas and compacted sediment in which they can burrow.

The ecology, life cycle, and population dynamics of the lobster in deep waters near offshore banks is far from complete. For example, the specific locations of settlement and nursery grounds remain unknown. Smaller sizes (in trawl surveys) in the shoal water areas of Georges Bank suggest that this is the likely area of settlement but, to date, no methods have been developed to test this assumption (Pezzack et al., 2009). Some work is underway with settlement collectors although, so far, it is limited to shallow coastal waters with some initial tests in deeper coastal waters.

Known Vulnerabilities

Though vulnerable at all life history stages, lobsters are most vulnerable during the 30-60 day planktonic larval stages when they are at or near the surface. The vertical distribution of larvae is not well understood, but data shows Stage I-II are distributed throughout the upper mixed layer (i.e. generally the upper 15 m) (Harding et al., 1987; Xue et al., 2008), while post larvae are concentrated in the upper 2 m, and generally in the upper 0.5m (Annis, 2005). Previous studies on the effects of contaminants (e.g. heavy metals and hydrocarbons) on larvae lobster have demonstrated biochemical, growth, and development effects, including changes in respiration, growth, feeding rates, and development times (Derby and Capuzzo, 1984). In addition, studies on the effects of contaminants on juvenile and adult lobster have demonstrated changes in burrowing behaviour and quality, food detection, molting frequency, respiration, and growth rates (Atema et al., 1982; Derby and Capuzzo, 1984).

Physical barriers (e.g., pipelines) resting on the bottom may also create barriers to the seasonal migration of lobster, which is important for growth and reproduction. The degree of impact may depend on the shape, size, and surface texture of the barrier, degree of burial, and the amount of open area beneath the barrier, as it crosses areas on uneven seafloor. Last, limited research has examined the impact of noise on lobster. Lobster exposed to high and low sound levels demonstrated changes in feeding and serum biochemistry, with effects sometimes being observed weeks to months after exposure (Payne et al., 2007; Payne et al., 2008).

Status Designation

American lobster is not listed pursuant to SARA and has not been evaluated by COSEWIC.

8.4 CRAB

8.4.1 Deep-Sea Red Crab

Distribution, Habitat, Abundance, and Predator and Prey

The deep-sea red crab, *Chaceon quinquedens*, is distributed along the continental shelf and slope of the western Atlantic. It is found between 200-1800 m water depth from Nova Scotia to Florida (Steimle et al., 2001). In Atlantic Canada, the deep-sea red crab is at the northern edge of its range, and populations are most dense on mud, sand and hard bottoms at water depths of 300-900 m and temperatures of 5-8 °C (DFO, 1998). Red crabs are opportunistic feeders that feed on squid, demersal and mid-water fish, sponges, hydroids, gastroids molluscs, polychaetes, and crustaceans (Stehlik, 1993; Steimle et al., 2001). No information is available on the diet of red crab larvae, but it is thought that zooplankton is the primary component of the larval diet (Steimle et al., 2001). The distribution of deep-sea red crab on Georges Bank, based on results from DFO research surveys, is shown in Figure 36.

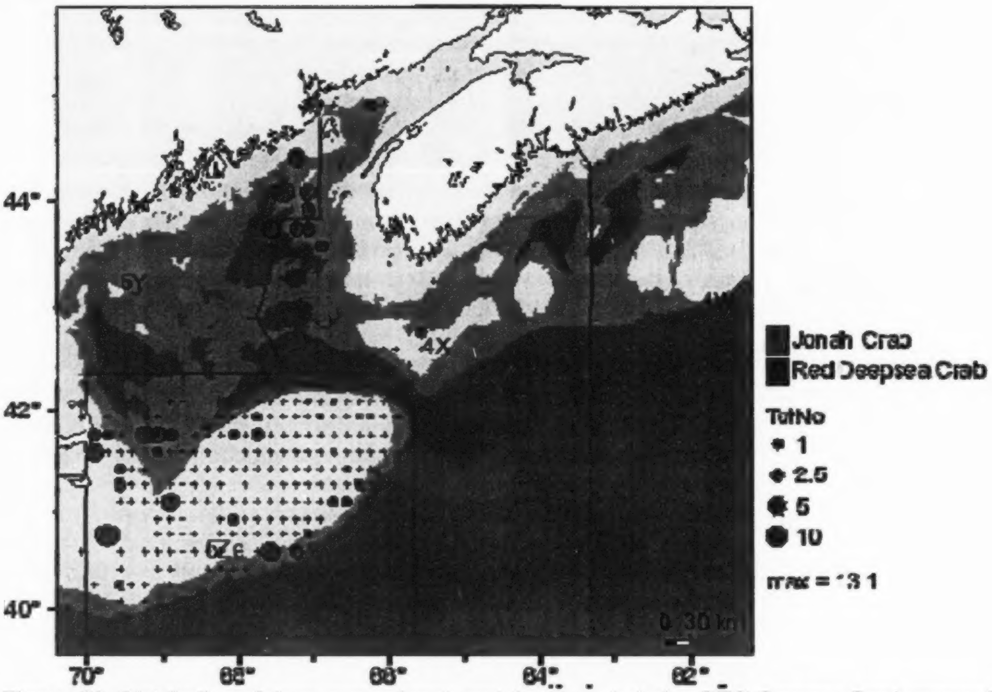


Figure 36. Distribution of deep-sea red crab and Jonah crab during DFO Georges Bank research surveys from 2002-2009.

Deep-sea red crab represents a data poor stock because they inhabit deep water, are rarely caught in trawl surveys, and little is known about their life history. The last assessment for red crab in the DFO Maritimes Region was completed by DFO in 1998. At that time, the offshore red crab fishing grounds were fully exploited with evidence of stock depletion on offshore banks. Catch rates have declined since the inception of the fishery, and the reduced landing and CPUE in 1997 suggest that red crab on Browns Bank may be depleted (DFO, 1998). Red crab in Canadian waters is at the northern edge of its range, and it is likely that much of the recruitment originates from the larger population in U.S. waters.

Sustained and reliable recruitment may not occur and, on the Scotian Shelf and northeast Georges Bank, it is fished as a pulse fishery by a small number of vessels. A 2003-2005 U.S. stock assessment indicated the biomass estimate of large male crab (greater than 114 mm carpace width) was approximately 13,800 t. This was 42% lower than 1974 estimates, while fishable male biomass, estimated to be 36,300 t, increased 5% over 1974 estimates. The current fishery, however, lands smaller red crabs in comparison to 1974. The estimated biomass of sexually-mature male and female red crab suggests a 29% and 244% increase from 1974, respectively (NEFSC, 2006a).

Population Structure Relative to Moratorium Area

Adult deep-sea red crabs are segregated incompletely by sex. Adult females generally inhabit shallower water than adult males, and juveniles tend to be deeper than adults, suggesting a deep-to-shallow migration as the crabs mature (NDPSWG, 2009). Tagging studies suggest red crabs move both vertically along the continental slope, covering a range of approximately 500 m, as well as laterally, covering an range of approximately 100 m (Steimle et al., 2001). Substantial numbers of red crab larvae have been collected from 12-270 km offshore on the Nova Scotia-Georges Bank area, with settlement thought to occur at the base of the continental shelf (DFO, 1998).

Life History, Location, and Timing

The deep-sea red crab is slow growing and reaches a maximum size of approximately 180 mm carapace width (CW). The size at maturity has been reported to primarily range from 80-130 mm CW (Steimle et al., 2001). Egg bearing females are present year-round off New England, with a peak incidence in November, and egg hatching is most prevalent from January to June. Females brood the eggs for up to nine months until the eggs hatch and the larvae are released into the water column (Steimle et al., 2001). The larvae require 23-125 days to develop through six stages before settling to the bottom. Settlement is thought to occur at the base of the continental shelf, with immediate upslope migration to warmer water likely occurring to enhance growth rates (DFO, 1998).

Known Vulnerabilities

No known vulnerabilities for deep-sea red crab.

Status Designation

Deep-sea red crab is not listed pursuant to SARA and has not been evaluated by COSEWIC.

8.4.2 Jonah Crab

Distribution, Habitat, Abundance, and Predator and Prey

Jonah crab, *Cancer borealis*, are found from Newfoundland to South Carolina and in the Bermudas at depths ranging from the intertidal to 800 m. In the offshore waters of Nova

Scotia, Jonah crab are found primarily at depths of 50-300 m and temperatures of 8-14 °C (DFO, 2009b). Its substrate preference changes from rocky substrates inshore to silt and mud off the continental slope. Jonah crab are opportunistic feeders that feed on squid, demersal and mid-water fish, sponges, hydroids, gastroids, molluscs, polychaetes, and crustaceans (Stehlik, 1993; Steimle et al., 2001). The distribution of Jonah crab on Georges Bank based on results from DFO research surveys is shown in Figure 36.

The offshore Jonah crab fishery began in 1995. Jonah crab is fished as a by-catch in the lobster fishery within Lobster Fishing Area (LFA) 41, more specifically Crowell Basin, Southwest and Southeast Browns Bank, Georges Basin, and Georges Bank. Abundance indicators (CPUE, number per tow in research vessel summer trawl surveys) and landings suggest that Jonah crab abundance has declined following the initiation of the fishery (Figure 37). Landings declined from 720 t in 1996-1997 to 14 t in 2007. There is insufficient information to evaluate production or recruitment trends for Jonah crab in LFA 41 (DFO, 2009b).

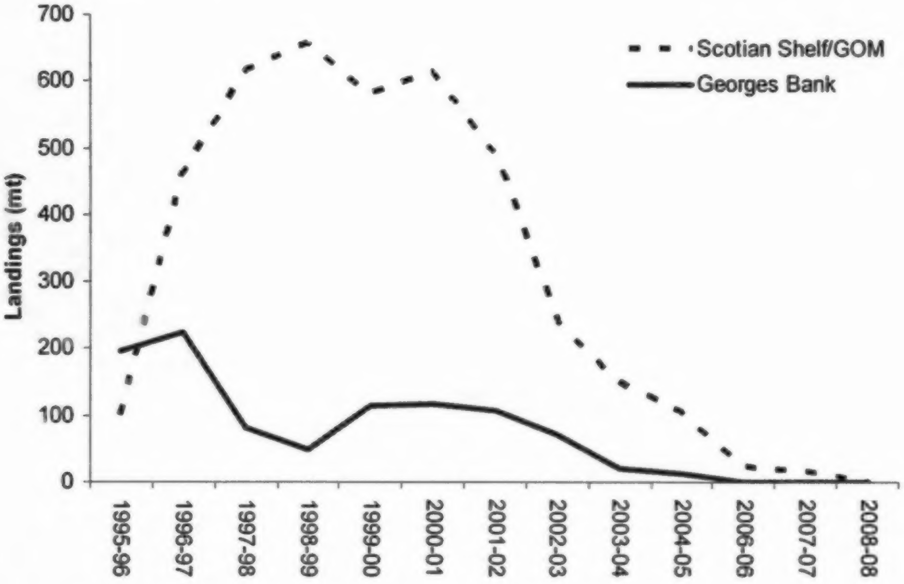


Figure 37. *Jonah crab landings in the Lobster Fishing Area 41 for the management of the Lobster/Jonah crab fishery.*

Population Structure Relative to Moratorium Area

Stock structure and migratory behaviour of Jonah crab are poorly understood, and their ability to redistribute themselves over the fishing grounds is unclear (DFO, 2009b). There have been some indications of migrations. Inshore movement from spring through fall, followed in winter by emigration to deeper warmer water toward the offshore edges of the shelf in Georges Bank and the Middle-Atlantic, has been reported (Stehilk et al., 1991). Size and sexual segregation with depth were reported in Virginia (DFO, 2009b). It is unclear, however, whether similar seasonal migrations and segregations occur in the Georges Bank area.

Life History, Location, and Timing

Very little biological information exists for Jonah crab in waters off of Nova Scotia. Knowledge of life history is geographically limited to waters off of New England and Chesapeake Bay. Preliminary analysis of Jonah crab maturity on the Scotia Shelf has shown that maturity of 50% males and females occurred at 128 mm and 92 mm CW (DFO, 2009b). The spawning period in the Mid-Atlantic Bight is suggested to be during late winter to early spring (DFO, 2009b). The female broods eggs in the swimmerets under the abdomen. The larvae develop through several plankton stages in the water column before settling to the bottom.

Known Vulnerabilities

No known vulnerabilities for Jonah crab.

Status Designation

The Jonah crab is not listed pursuant to SARA and has not been evaluated by COSEWIC.

8.5 SQUID

8.5.1 Northern Shortfin Squid

Distribution, Habitat, Abundance, and Predator and Prey

The northern shortfin squid, *Illex illecebrosus*, is a highly migratory and transboundary species that is distributed in the northwest Atlantic from Newfoundland to Florida. It is considered to constitute a single stock throughout its range. The northern component of the stock extends from Newfoundland to the southern Scotia Shelf and the southern component extends from the Gulf of Maine to Florida (Hendrickson and Holmes, 2004). The species inhabits the continental shelf and slope waters from Cape Hatteras to Georges Bank and the Scotian Shelf primarily during spring through autumn. During late autumn, squid migrate off the continental shelf and southward. Species distribution and abundance are strongly related to oceanographic factors. During the spring, squid are most abundant over water depths of 120-400 m and temperature range of 10-14 °C. In autumn, squid are most abundant over a bottom temperature range of 8-13 °C, with abundance increasing with depth between 31-140 m and a secondary peak between 200-300 m (Hendrickson and Holmes, 2004).

Northern shortfin squid feed primarily on fish and crustaceans, but cannibalism of small individuals by larger females also occurs, particularly during autumn. They exhibit diel vertical migrations, and both juveniles and adults feed primarily at night in the upper levels of the water column. An ontogenetic shift in diet from a predominance of crustaceans to fish and squid is evident in squid from both components. Fish prey consists of early life history stages of Atlantic cod, Arctic cod and redfish, sand lance, mackerel, Atlantic herring, haddock, sculpin, and longfin inshore squid (Hendrickson and Holmes, 2004).

The abundance of northern shortfin squid commercially-exploited in the U.S. Gulf of Maine area is highly variable from year to year, due to their short life span and highly migratory nature. Abundance appears to be closely tied with that of their prey, competitors, and shifts in the geographic position of the Gulf Stream and related fronts. In NAFO Division 4, a period of high productivity and relative abundance from 1976-1981 occurred between two low productivity periods of 1970-1975 and 1982-2004. A large increase in the biomass index during 2004 was followed by a sharp decline of 0.7 kg per tow in 2005 that was well below the 1982-2004 average of 3.0 kg per tow (NEFSC, 2006b). In NAFO Divisions 5 and 6, survey results indicate that periods of high relative abundance occurred from 1976-1981 and 1987-1990, averaging 18.8 and 19.5 squid per tow, respectively. An intermediate level of abundance occurred during 1991-1998, averaging 8.7 squid per tow. Survey indices increased after 1999 and attained a record high in 2003, but they declined sharply in 2004 to the level observed in 2002. In 2005, survey indices increased slightly (Hendrickson, 2004).

Population Structure Relative to Moratorium Area

Seasonal distribution patterns suggest that annual migrations from the slopewater onto the shelf in the spring and off the shelf in the autumn occur simultaneously along the entire length of the continental shelf edge. Tagging studies have demonstrated a south-eastward migration of individuals during autumn. Georges Bank is on their migration route to the Gulf of Maine, and it may serve as an important feeding area. However, the migration patterns between northern and southern stock components remain unknown, and the offshore fraction of the population is not well understood (Hendrickson, 2004).

Life History, Location, and Timing

Northern shortfin squid live for less than one year (115-215 days), exhibit variable growth rates, high natural mortality rates, and a protracted spawning season in which overlapping microcohorts continuously enter the populations throughout the year over a wide geographic area. Spawning occurs throughout most of the year from October through June. The only confirmed spawning area is located in the Mid-Atlantic Bight at depths of 113 to 377 m, where the winter cohort spawns during late May (Hendrickson, 2004). Spawning may also occur offshore in the Gulf Stream/Slope Water frontal zone (O'Dor and Balch, 1985) and south of Cape Hatteras during winter (Dawe and Beck, 1985).

Shortfin squid is a semelparous, terminal spawner with spawning and death occurring within several days of mating. Female squid may release multiple neutrally buoyant, gelatinous egg balloons with hatching occurring 8 to 16 days thereafter (Hendrickson and Holmes, 2004). Larvae may remain within the remnants of the egg mass to utilize the nutrients as a food source. Larvae are carried northward by the Gulf Stream and live in the frontal zone between the Gulf Stream and slope water until they reach approximately 10 cm in length (Dawe and Hendrickson, 1998). Size and age-at-maturity increase with latitude and are correlated with decreases in water temperature (Hendrickson, 2004).

Known Vulnerabilities

Squid showed a strong startle response to nearby air-gun start up and evidence that they would significantly alter their behaviour at an estimated 2-5 km from an approaching large seismic source (McCauley et al., 2000a).

Status Designation

Northern shortfin squid is not listed pursuant to SARA and has not been evaluated by COSEWIC.

8.5.2 Longfin Inshore Squid

Distribution, Habitat, Abundance, and Predator and Prey

Longfin inshore squid, *Loligo pealeii*, a schooling species, are distributed from Newfoundland to the Gulf of Venezuela. The principal concentrations, however, occur from Georges Bank to Cape Hatteras. The population is considered to constitute a single stock throughout its range (Brodziak, 1995). Adult longfin inshore squid inhabit the continental shelf and upper slope to depths of 400 m, although depth varies seasonally. In spring, they occur at depths of 110-200 m, in summer and fall they inhabit inshore waters as shallow as 6-28 m, and in winter they inhabit offshore waters to depths of 365 m. They are found on mud or sand/mud substrate at surface temperatures ranging from 9-21 °C and bottom temperatures ranging from 8-16 °C (Jacobson, 2005).

Longfin inshore squid form large schools based on size prior to feeding and make diurnal vertical migrations up through the water column at night. Their diet changes with size. Small immature individuals feed on planktonic organisms including euphausiids, arrow worms, small crabs, polychaetes, and shrimp, while larger individuals feed on crustaceans, small fish, and squid. Fish prey species include silver hake, mackerel, herring, menhaden, sand lance, bay anchovy, menhaden weakfish, and silversides. Seasonal and inshore/offshore differences in diet were reported for longfin inshore squid. In offshore waters in the spring, the diet is composed of crustaceans (mainly euphausiids) and fish. During the fall, in inshore waters, the diet is composed almost exclusively of fish (Jacobson, 2005).

Annual autumn relative abundance indices are highly variable, partially because relative abundance is affected by oceanographic conditions (Hendrickson and Jacobson, 2006). During 1967-2005, survey indices varied with little trend, except that relative abundance was consistently below the time series average during 1968-1972 and above the time series average during 1999-2002. After 2002, relative abundance declined and was below average in 2005. The stock found between the northern edge of Georges Bank to Cape Hatteras was last assessed by the NEFSC in 2001. Production model results indicated that the quarterly biomass ranged between 14,000-27,000 t and averaged 21,800 t during 1987-2000 (Hendrickson and Jacobson, 2006).

Population Structure Relative to Moratorium Area

Longfin inshore squid undergo seasonal migrations that appear to be related to bottom water temperatures. They migrate offshore along the edge of the continental shelf during late autumn and return inshore during the spring and early summer (Jacobson, 2005). When inshore waters are coldest during winter and early spring, the population concentrates along the outer edge of the shelf. The inshore movement to the shelf areas takes place when water temperatures are increasing, which begins in the south and proceeds north along the coast. Spawning has been reported to occur during this migration. In Canadian waters, spawning has been reported from early spring and late summer on the Scotian Shelf and Georges Bank (Jacobson, 2005).

Life History, Location, and Timing

Longfin inshore squid have a lifespan of less than one year (approximately 9 months), grow rapidly, and are sexually dimorphic. Males grow more rapidly and reach larger sizes at age than females. In addition, growth is dependent on temperature and is highest for individuals hatched in summer (Brodziak and Macy, 1996). Longfin inshore squid spawn year round with seasonal peaks that vary among years and geographic areas, though most eggs are spawned in May and hatched in July. Spawning has been reported from August to September in the Bay of Fundy, May to August in New England waters, late spring to early summer in the Middle Atlantic, and early spring and late summer on the Scotian Shelf and Georges Bank (Jacobson, 2005). Females lay clusters of gelatinous egg capsules, each containing 150-200 eggs, on rocks and aquatic vegetation usually at depths less than 50 m. The eggs hatch in 11-27 days, depending on temperature, to produce planktonic larvae that move deeper as they grow. The shift from inhabiting surface waters to a demersal lifestyle occurs at 45 mm CW (Jacobson, 2005).

Known Vulnerabilities

Squid showed a strong startle response to nearby air-gun start up and evidence that they would significantly alter their behaviour at an estimated 2-5 km from an approaching large seismic source (McCauley et al., 2000a).

Status Designation

Longfin inshore squid is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.0 FINFISH

This section describes finfish species of commercial value, species with COSEWIC or SARA status, or other finfish species considered of interest to this marine ecosystem overview. Select finfish species are summarized in the Appendix.

9.1 HERRING

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic herring, *Clupea harengus*, range from Labrador to Cape Hatteras in the western Atlantic (Figure 38). Herring is a pelagic schooling species known to undertake extensive seasonal migrations for summer feeding and over-wintering, but it can be found almost year round in most areas. Adult herring are assumed to home to native spawning grounds where they aggregate annually for spawning. Major spawning areas are restricted to the northern regions between Cape Cod and northern Newfoundland (Scott and Scott, 1988). Bottom habitat is critical to spawning and varies from region to region. Typically, spring spawners spawn in near shore shallow waters, while fall spawners spawn in offshore deeper water.

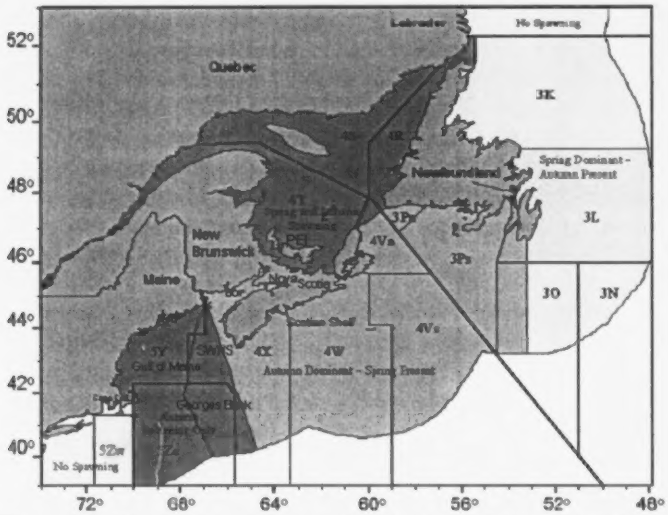

52°
50°
48°
46°
44°
42°
40°
72°
68°
64°
60°
56°
52°
48°
Labrador
No Spawning
Quebec
3K
4R
Newfoundland
Spring Dominant - Autumn Present
4T
PEI
3Pn
4Vn
3L
3Ps
New Brunswick
Maine
Nova Scotia
3O
3N
Scotian Shelf
4Vs
5Y
Gulf of Maine
SWNS
4X
4W
Autumn Dominant - Spring Present
Georges Bank
5Zw
No Spawning

Figure 38. Distribution and spawning strategy of Atlantic herring stocks along the western Atlantic (Melvin et al., 2009).

Atlantic herring are a key forage species on Georges Bank. They are critical to the transfer of energy from one trophic level to another in the ecosystem. Almost every marine fish species in the region consumes herring at some stage in their life cycle. The main food sources for herring are the copepods *Pseudocalanus sp.*, *Paracalanus parvus*, and *Centropages typicus* (Cohen and Lough, 1983). The adult diet is dominated by euphausiids, chaetognaths, and copepods (Bigelow and Shroeder, 1953). Smaller juvenile herring (42 -130 mm) eat larval stages of *Calanus* along with the copepods *Centropages* and *Pseudocalanus* and the larvae of mysids and decapods. Larval herring (i.e. 12-42 mm in length) prefer *Pseudocalanus* at all of its stages, as well as the eggs and larvae of other copepods. Yolk-sac larvae (i.e. 5-7 mm in length) and larvae up to 12 mm in length consume whatever zooplankton of appropriate size are abundant, including the eggs and larvae of ctenophores, siphonophores, polychaetes, and chaetognaths.

The Georges Bank herring stocks collapsed in the late 1970s due to foreign and domestic fleet over-fishing and poor recruitment. Herring was virtually absent on the Bank until the early 1980s. From the late 1980s and mid 1990s, the stock continued to be rebuilt and gradually reoccupied its historical spawning range. The stock has remained at a relatively high level since 1997. Georges Bank and the Gulf of Maine herring are assessed as a stock complex. In recent years, herring from Georges Bank are thought to contribute more than 80% of adult biomass to the total Gulf of Maine stock complex (Overholtz et al., 2004; Melvin and Stephenson, 2007). Figure 39 exhibits the trends in biomass and recruitment for the herring stock complex. Stock biomass (2+, January 1) increased steadily from about 111,600 t in 1982 to approximately 830,000 t in 1997. It has fluctuated since then and was estimated to be 652,000 t at the beginning of 2008 (Figure 39). Recruitment at age 2 from the 2004 and 2006 year classes appeared weaker than the long-term (1967-2005) average of 2.3 billion fish. The 2005 year-class abundance that was estimated is above average abundance at 3.3 billion fish.

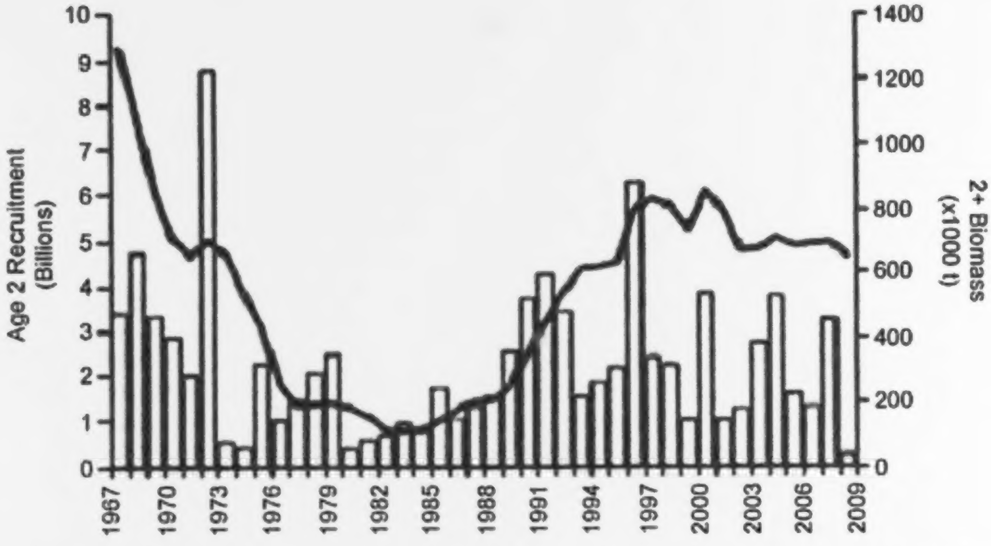


Figure 39. *Age 2 recruitment (bars) and Age 2+ biomass (line) per year for Gulf of Maine/Georges Bank herring (TRAC, 2009a).*

Population Structure Relative to Moratorium Area

Herring populations of the western Atlantic exhibit considerable discreteness and limited connectivity that, on a temporal and spatial scale, is relevant to resource management, the ecosystem, and offshore development. This implies that activities that impact one population may have a limited impact on the others, even though they interact during non-spawning periods. Georges Bank herring undertake extensive annual migrations from their southern over-wintering locations to their feeding and spawning grounds on Georges Bank during the summer and fall. Herring from Georges Bank and the Gulf of Maine, which move south of Cape Cod during mid- to late-winter, begin migrating from their over-wintering areas to the southern part of Georges Bank with their numbers increasing as summer approaches. The spawning distribution extends along the entire northern reach from the Great South Channel to the northeast peak. Herring remain on the Bank for feeding and spawning until late-October to early-November when they disperse and slowly move southward to over-wintering areas. Bottom trawl survey catches demonstrating the distribution of adults during the spawning period (i.e. September-November), which can be considered a proxy for the spatial scale of spawning area, are shown in Figure 40 (Melvin and Stephenson, 2007).

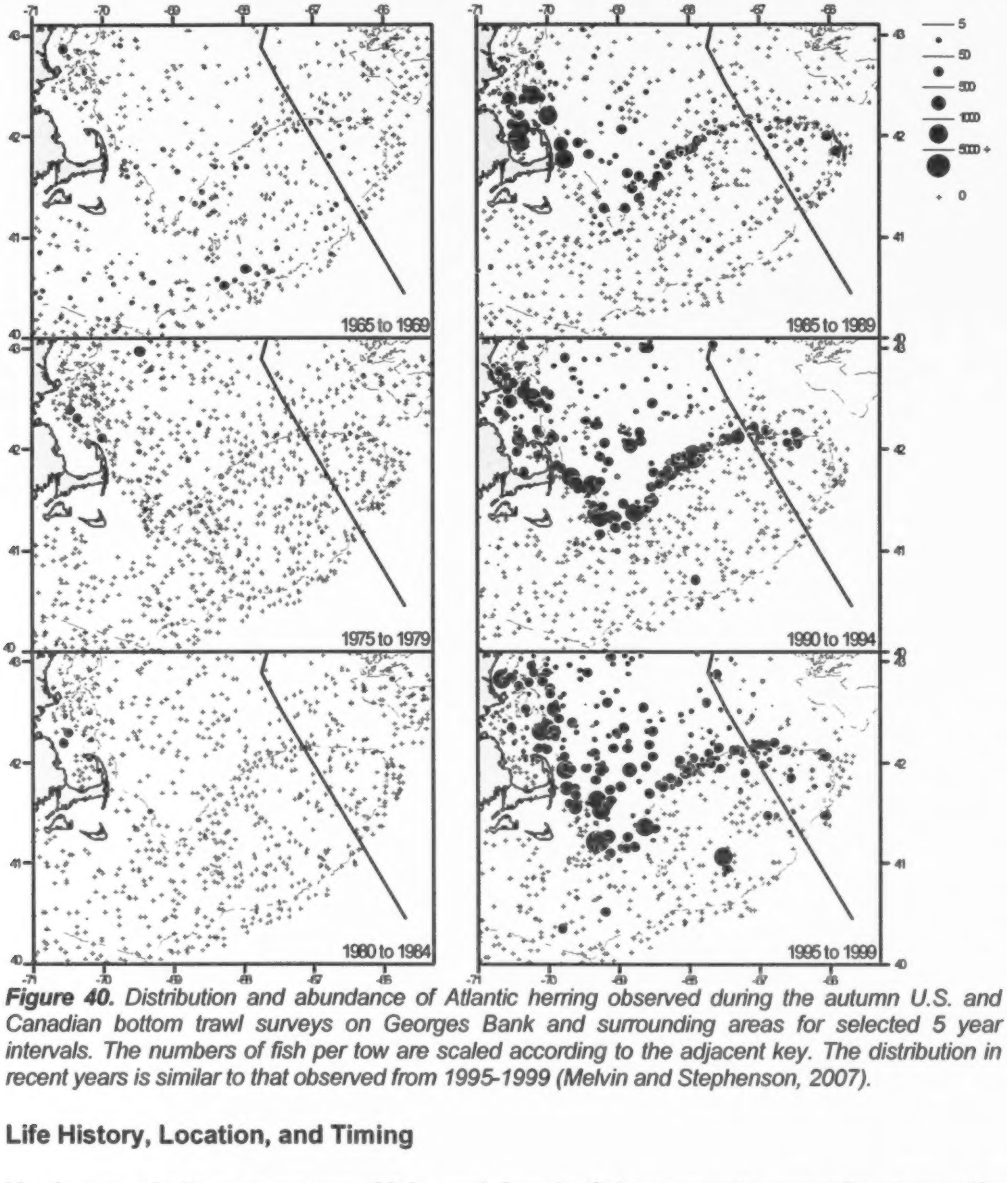


Figure 40. Distribution and abundance of Atlantic herring observed during the autumn U.S. and Canadian bottom trawl surveys on Georges Bank and surrounding areas for selected 5 year intervals. The numbers of fish per tow are scaled according to the adjacent key. The distribution in recent years is similar to that observed from 1995-1999 (Melvin and Stephenson, 2007).

Life History, Location, and Timing

Herring are bottom spawners. Male and female fish aggregate annually at specific locations to spawn over a period of 1-1.5 months. Spawning occurs in waves and multiple spawning events can occur at the same location during a spawning season. The eggs are negatively buoyant and adhesive and attach to the gravel substrate or benthic vegetation for 10-12 days before hatching, depending upon water temperature (Figure 41). Once hatched, larval herring become pelagic and can be found throughout the water column.

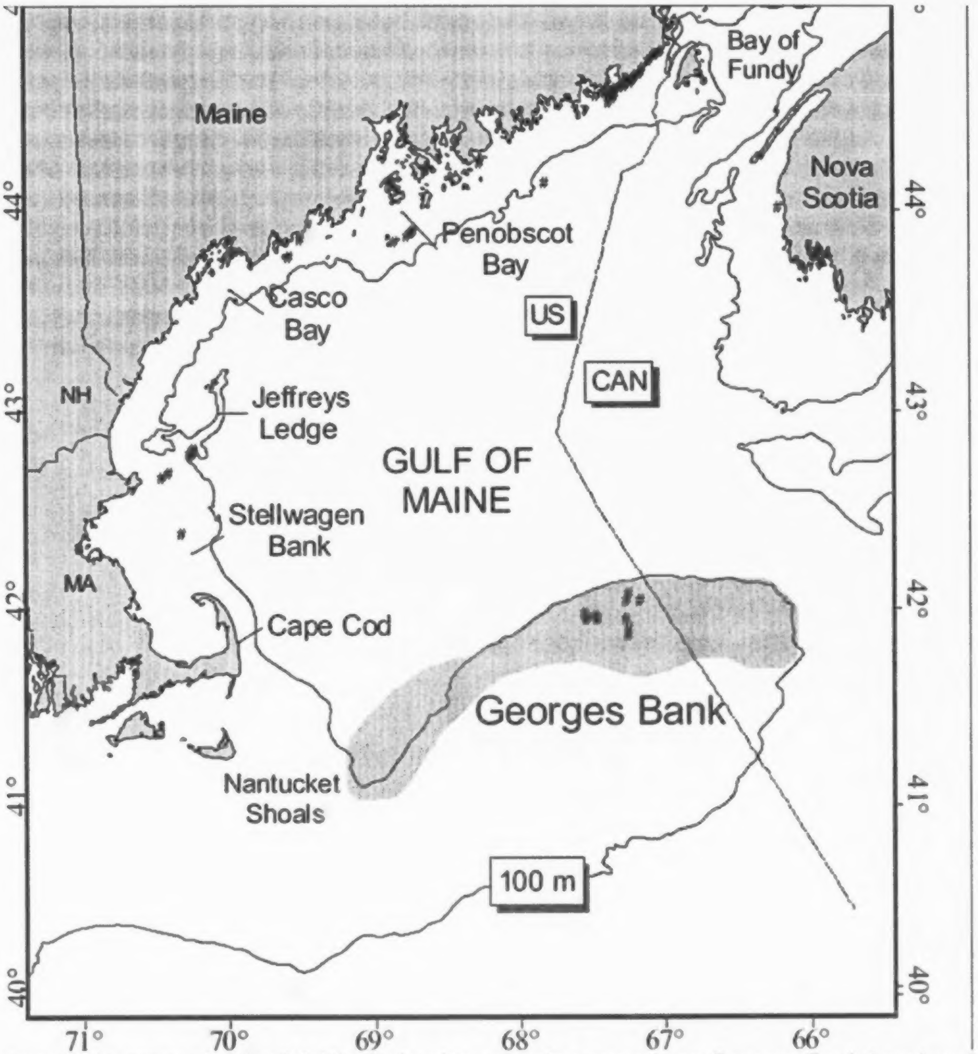

Maine
Bay of Fundy
Nova Scotia
Penobscot Bay
Casco Bay
US
CAN
NH
Jeffreys Ledge
GULF OF MAINE
Stellwagen Bank
MA
Cape Cod
Georges Bank
Nantucket Shoals
100 m
44°
43°
42°
41°
40°
71°
70°
69°
68°
67°
66°

Figure 41. Location of potential Atlantic herring spawning grounds on Georges Bank (grey) and the location of egg observations on bottom, as indicated by number sign (#) (Stevenson and Scott, 2005).

On Georges Bank, the larval stage (October-March) lasts up to 6 months, after which they metamorphose into juvenile fish at a length 40-50mm. The distribution of larvae is consistent with the general winter circulation patterns. A large portion of the herring larvae remain on the Bank throughout the larval stage, including the Canadian portion (Figure 42). There is little, if any, dispersion into the coastal waters of the Gulf of Maine. Some larvae from Nantucket Shoals and Georges Bank drift to the southwest as far south as New Jersey (Lough et al., 1985; Stevenson and Scott, 2005).

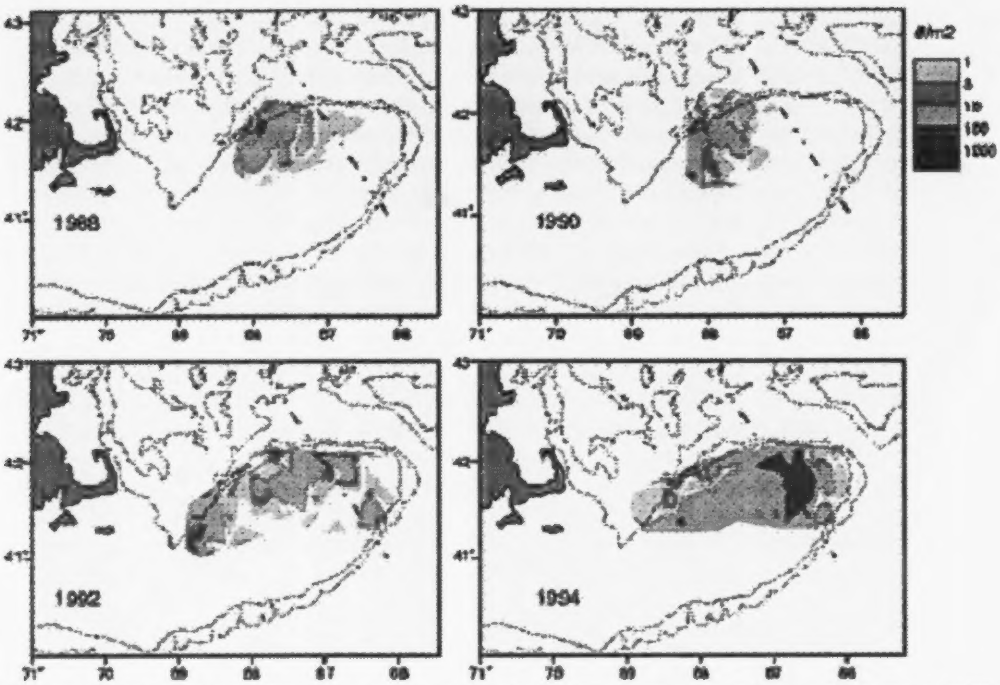


Figure 42. Distribution of recently hatched Atlantic herring larvae on Georges Bank from 1988-1994. The data represent the most recent Canadian larval data available. The annual larval survey on Georges Bank was concluded in 1996 (Melvin and Stephenson, 2007).

Juvenile herring from the Gulf of Maine and coastal Maine are known to migrate north during the summer to waters of southern New Brunswick, where they make an unknown contribution to the weir fishery. Georges Bank juvenile herring can be found on the Bank throughout the year, but many are thought to move inshore to coastal Maine and the northwestern portion of the Bay of Fundy. This large nursery area with fish from several stocks supports one of the oldest fisheries in Atlantic Canada.

Known Vulnerabilities

Herring is known to concentrate their spawning in relatively small and select locations. As such, they are vulnerable to any activities that interact with, disturb, or contaminate the ocean bottom. In addition, herring can detect a broad range of frequencies, likely, better than most fish. This suggests that noise may have an impact on their behaviour by altering migration patterns, disrupting spawning, and/or changing feeding behaviour. Changes in behaviour may not only affect herring but also other species in the ecosystem that depend on herring as forage.

Status Designation

Herring is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.2 MACKEREL

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic mackerel, *Scomber scombrus,* is a small schooling pelagic fish species. It is found on both sides of the North Atlantic Ocean, including the Baltic Sea. In the western Atlantic, Atlantic mackerel range from Labrador to Cape Hatteras, North Carolina (Figure 43). There is thought to be two main spawning components. In Canadian waters, there is a northern group that spawns mainly in the southern Gulf of St. Lawrence during the months of June and July. This spawning period is preceded by a long migration that begins early in spring in the Gulf of Maine and Georges Bank area (thought to be initiated when water temperatures reach approximately 8 °C). In U.S. waters, there is a southern group that spawns primarily in the Mid-Atlantic Bight during the months of April and May. Both groups winter between Sable Island and Cape Hatteras in waters generally warmer than 7 °C (Studholme et al., 1999). Mackerel are opportunistic feeders and prey most heavily on crustaceans, such as copepods, krill, and shrimp. They also eat squid and some fish. They are fed upon by a large number of fish and cetacean species (Studholme et al., 1999).

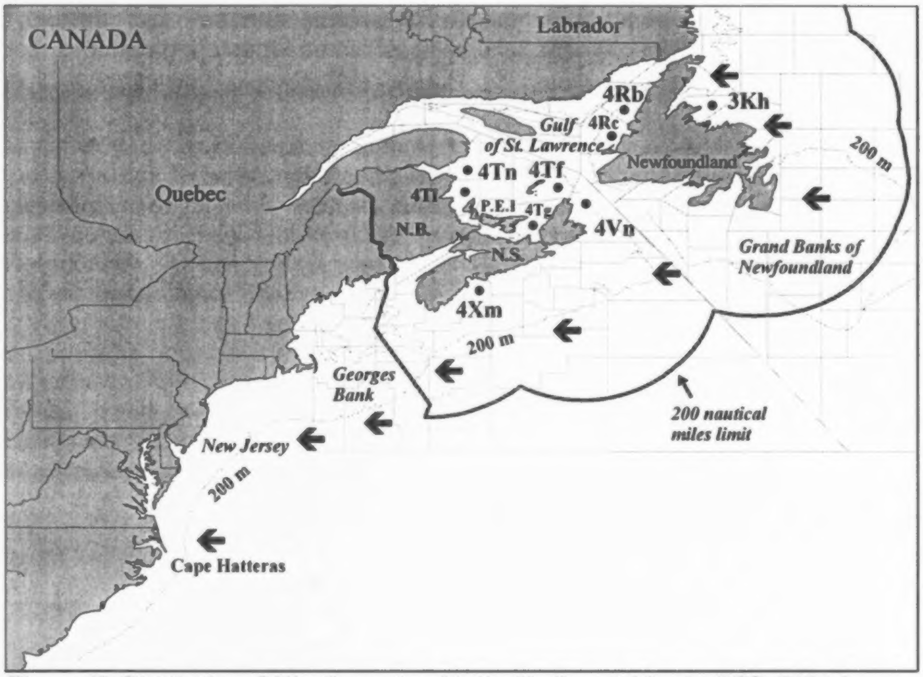


Figure 43. *Distribution of Atlantic mackerel in the Northwest Atlantic (DFO, 2004a).*

The Atlantic mackerel stock is thought to have collapsed in the late 1970s due to foreign fleet fishing efforts. Overall, spawning stock biomass has increased since 1978 and the stock as a whole is thought to have recovered in the late 1980s and 1990s. There was a very strong year-class of mackerel in 1999, but more recent year-classes do not appear to have been as strong. The northern component of mackerel that spawn in the southern Gulf of St. Lawrence has shown signs of a change in distribution, potentially in response to changes in water temperature. For the Gulf of St. Lawrence spawning component, there has been a reduction in the daily and total egg production since 2002. In 2007, spawning biomass was estimated at 76,532 t, which represents one of the lowest values of the series (NEFSC, 2006b; DFO, 2008b). Recent surveys also show an apparent lack of older fish.

Population Structure Relative to Moratorium Area

Mackerel are not caught in significant quantities in the Georges Bank bottom trawl survey, though they are thought to over-winter in the deeper waters of the continental shelf with migrations through this area heading north in spring and south in the fall. When they are caught in the survey, they tend to be found along the edges of the Bank (Figure 44).

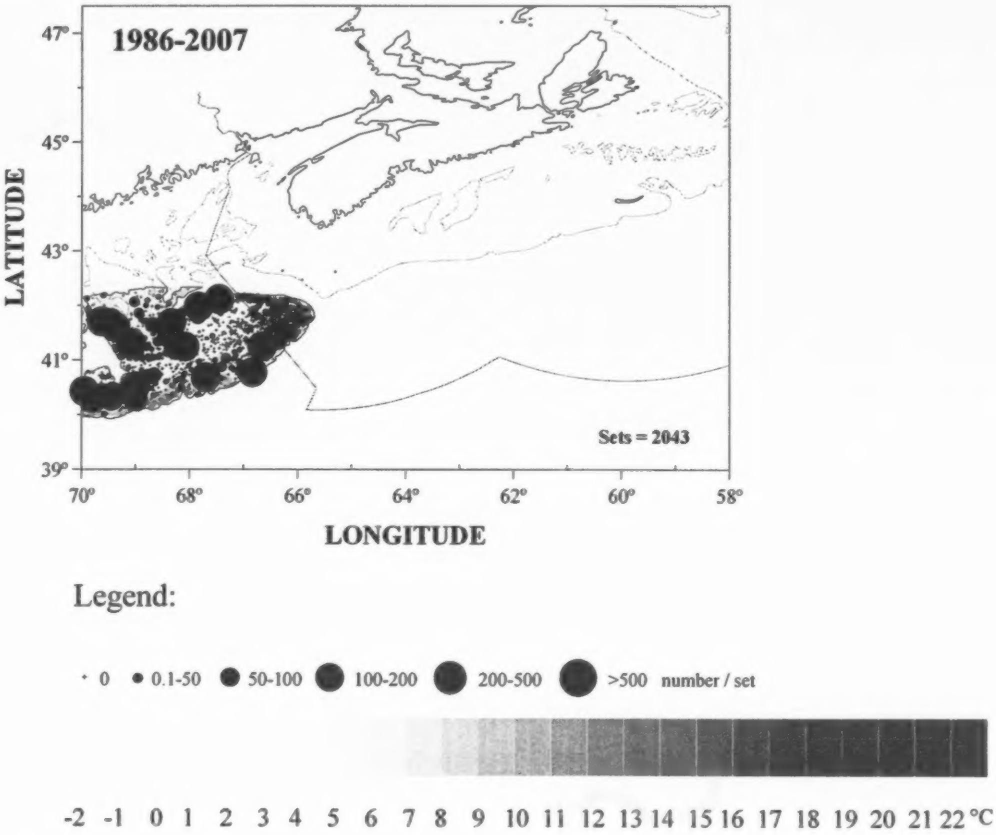

1986-2007
Sets = 2043
47°
45°
43°
41°
39°
LATITUDE
70°
68°
66°
64°
62°
60°
58°
LONGITUDE
Legend:
0
0.1-50
50-100
100-200
200-500
>500
number / set
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 °C

Figure 44. Composite map of mackerel catches by bottom trawl on Georges Bank from 1986-2007.

Life History, Timing, and Locations

Atlantic mackerel have a life span of approximately 20 years. Their growth is rapid and they can reach a maximum size of 42 cm in length and weight of 1.0 kg. They reach maturity between ages 2-3. Mackerel spawn between 5 and 7 batches of eggs per year. Eggs generally float in the surface water and hatch in 4-7.5 days depending on water temperature (Studholme et al., 1999).

Known Vulnerabilities

Mackerel eggs float in surface waters of temperatures 9 °C and higher and, as such, may be susceptible to impact from noise, oil, or other contaminants. Mackerel do not have a swim bladder and are not believed to be as sensitive to sound pressure as those fish species with a swim bladder.

Status Designation

Atlantic mackerel is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.3 SAND LANCE

Distribution, Habitat, Abundance, and Predator and Prey

Two species of sand lance occur in the northwest Atlantic, the American sand lance (*Ammodytes americanus*) and the northern sand lance (*Ammodytes dubius*). These species are similar and difficult to distinguish (Breeze et al., 2002). Sand lance is a bottom dwelling species found on both sides of the Atlantic Ocean. In the northwest Atlantic, they range from west Greenland to Cape Hatteras, North Carolina. *A. americanus* occurs in inshore waters from Hudson Bay and the Hudson Strait south to Virginia. In the Gulf of Maine, it is found at depths of 6-20 m (Scott and Scott, 1988; Robards et al., 1999). *A. dubius* occurs from Hudson Bay and Greenland south to the Scotian Shelf. It has a more offshore distribution than *A. americanus*, although the two species co-occur. Scott (1982) considered 73-90 m water depth to be the preferred depth range of *A. dubius.* The highest concentrations of sand lance on the Scotian Shelf have been found in depths less than 50 m at temperatures of 1-5 °C. Historical surveys indicate a distribution pattern with concentrations over most of the offshore banks, including Georges Bank and Browns Bank (DFO, 1996a) (Figure 45). Both species live on sandy bottoms and burrow in the sand to rest and escape predators (Scott and Scott, 1988).

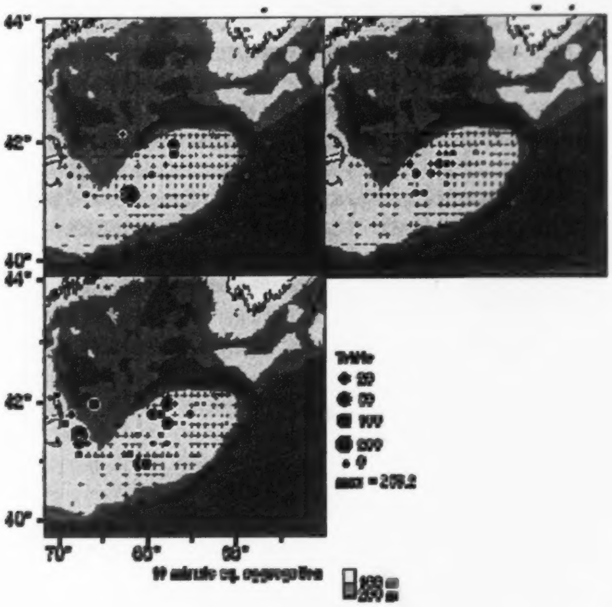


Figure 45. *Distribution of sand lance caught in Georges Bank Research Survey from 1995-2009.*

Sand lance is considered a planktonic feeder (DFO, 1996a). Larvae hatch prior to the spring bloom and feed on phytoplankton, diatoms, and dinoflagellates. On Georges Bank and in the Gulf of Maine region, copepods (mainly *Calanus finmarchicus*) are their primary food source, with euphausiids and polychaete larvae also comprising a significant portion of the diet (DFO, 1996a). In addition, mysids, cumaceans, amphipods, snails, small clams, isopods, and small crabs also contribute to the diet of sand lance (Scott and Scott, 1988). At night sand lance move up into the water to feed, commonly forming dense schools. They return to the bottom during the day to avoid predators (DFO, 1996a). Their annual recruitment is highly variable. Peaks in abundance were evident in the early-1970s and late-1980s to early-1990s (DFO, 1996a). In NAFO Divisions 4VWX, sand lance biomass has followed a declining trend since 2000, but remains above average for the series in 2008 (Clarke and Emberley, 2009) (Figure 46).

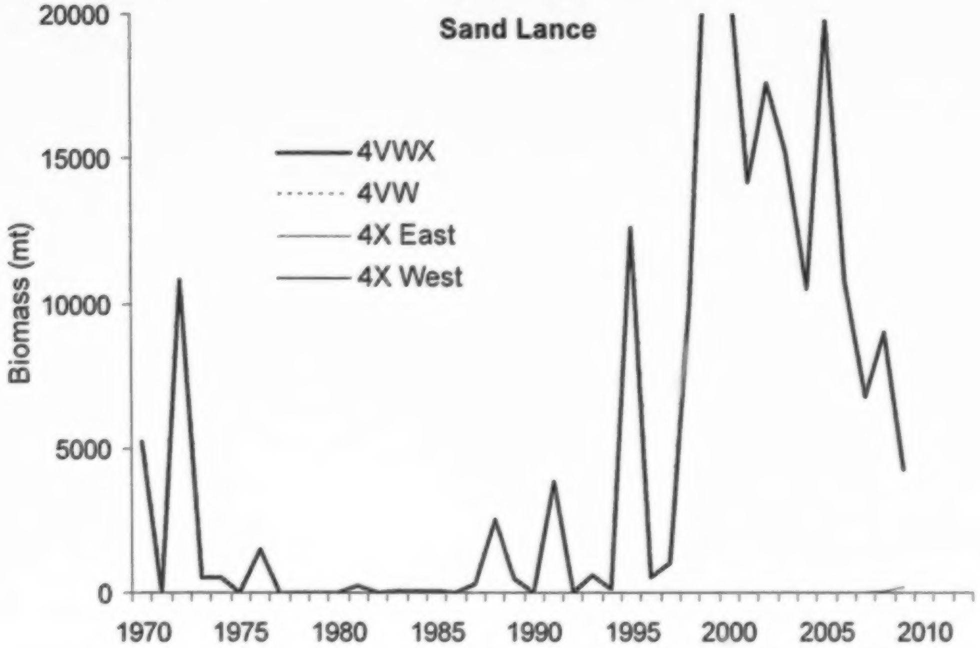


Figure 46. Biomass estimate for northern sand lance from the summer RV survey.

Population Structure Relative to Moratorium Area

The stock structure of sand lance is unknown and compounded by two species that co-occur and whose taxonomic separation is poorly resolved. There is no evidence of long-distance migration and they are, as a result, considered a relatively non-migratory species.

Life History, Location, and Timing

Sand lances in the northwest Atlantic have longevity of approximately 9 years and mature towards the end of their second year. Sand lances have a well defined breeding season, starting in November, ending before March, and peaking between December and January. They spawn on sand in shallow water during the winter months with eggs considered to be demersal and adhesive, adhering to sand and gravel on the bottom (Scott and Scott, 1988). Larvae have been concentrated on Sable Island and Middle banks, indicating these are likely major spawning areas (DFO, 1996a). Larvae ascend to surface waters where they remain until they are 35 mm at which time they descend to the bottom (Scott and Scott, 1988).

Known Vulnerabilities

Sand lance burrows into sandy bottoms and have demersal and adhesive eggs. As such they are vulnerable to any activities that interact with, disturb, or contaminate the bottom substrate. Sand lance is an important part of the marine food web, as it is a food source for marine mammals and groundfish species including cod, haddock, and pollock. Any impact on behavior may not only affect sand lance, but also other species that depend on them for forage.

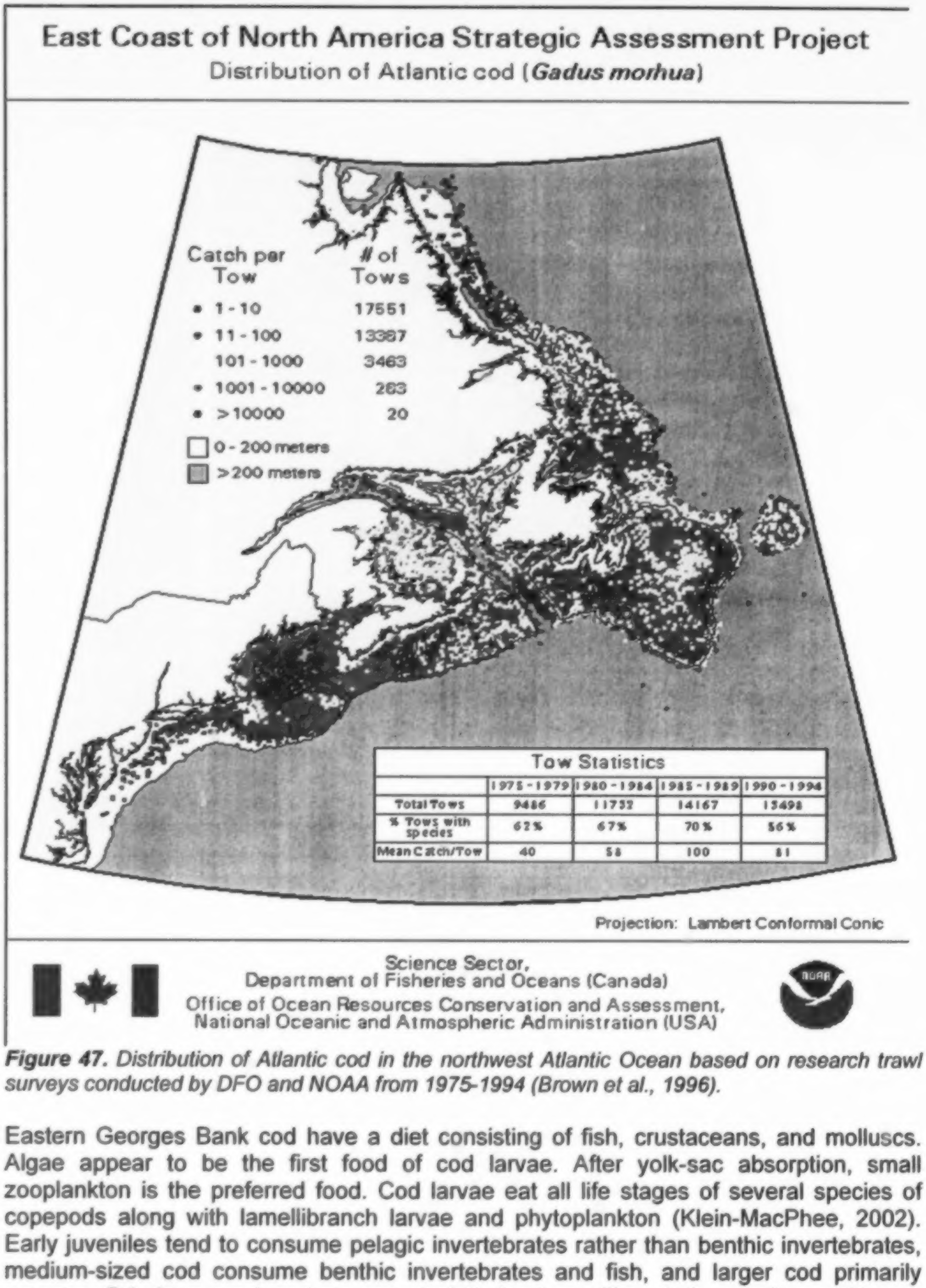
Status Designation

Sand lance is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.4 ATLANTIC COD

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic cod, *Gadus morhua*, is a demersal gadoid fish species that is found in the northwest Atlantic Ocean from Greenland to Cape Hatteras, North Carolina (Figure 47). Cod on Georges Bank is the most southerly cod stock in the world (Wise, 1958). Cod occur on rocky and pebbly grounds, gravel, sand, and a particularly gritty type of clay with broken shells. They are typical groundfish, usually found within 2 m or so of the bottom. Large cod remain closer to the bottom than smaller cod (Klein-MacPhee, 2002). They move in schools from deeper to shallower waters in seasonal cycles thought to be triggered by temperature, food, and spawning behavior. The gravel pavement of the Northeast Peak, which covers an underlying sandy deposit, is an important nursery ground for juvenile cod and is habitat that provides an important food source for demersal fish.


East Coast of North America Strategic Assessment Project
Distribution of Atlantic cod (*Gadus morhua*)
Catch per Tow
# of Tows
1 - 10 17551
11 - 100 13387
101 - 1000 3463
1001 - 10000 283
>10000 20
0 - 200 meters
>200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	15498
% Tows with species	62%	67%	70%	56%
Mean Catch/Tow	40	58	100	81

Figure 47. *Distribution of Atlantic cod in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Eastern Georges Bank cod have a diet consisting of fish, crustaceans, and molluscs. Algae appear to be the first food of cod larvae. After yolk-sac absorption, small zooplankton is the preferred food. Cod larvae eat all life stages of several species of copepods along with lamellibranch larvae and phytoplankton (Klein-MacPhee, 2002). Early juveniles tend to consume pelagic invertebrates rather than benthic invertebrates, medium-sized cod consume benthic invertebrates and fish, and larger cod primarily consume fish. In general, cod are opportunistic feeders, although they prefer sand lance, Cancer crab, and herring (Lough, 2004).

Based on the 2009 assessment (two assessment model formulations 'split M 0.2' and 'split M 0.5' have been used), the adult population biomass (ages 3+) of eastern Georges Bank cod declined from approximately 50,000 t in 1990 to less than 10,000 t in 1995. They fluctuated between 6000-13,000 t before decreasing in 2005 to somewhere in the range of 3800 t-6000 t. At the beginning of 2009, the adult population biomass increased to somewhere in the range of 8700 t-12,000 t (Figure 48). Resource productivity is currently poor due to low recent recruitment and low weights-at-age (TRAC, 2009b).

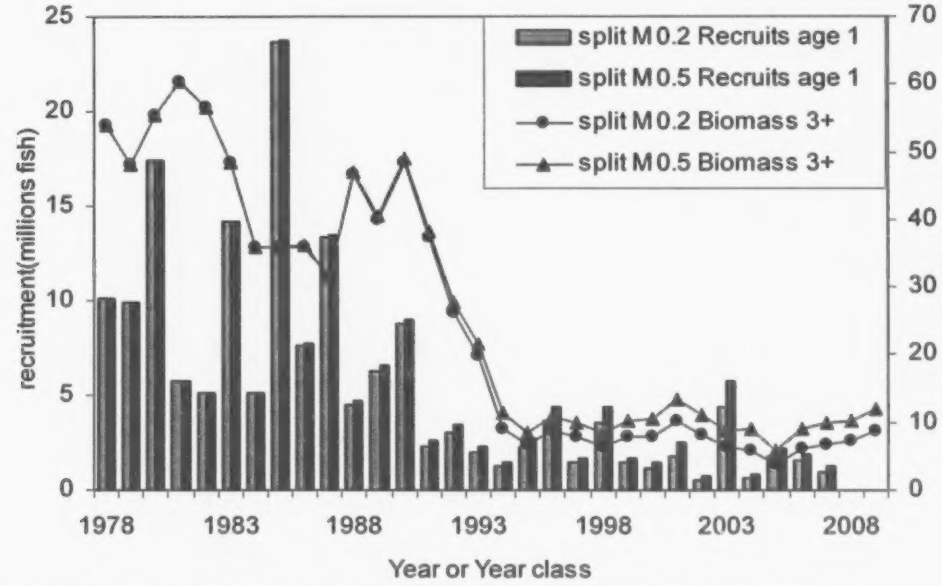


Figure 48. Biomass (lines) and recruitment (bars) of eastern Georges Bank cod.

Population Structure Relative to Moratorium Area

In the Gulf of Maine and Georges Bank region, the population structure of cod is complex, characterized by offshore sub-populations found on Georges Bank, Browns Bank, Great South Channel-Nantucket shoals, and localized coastal sub-populations that have limited connection to the offshore banks (Figure 49). The cod stock structure found on Georges Bank and adjacent areas is also complex, involving seasonal migration patterns and mixing grounds that facilitate exchange between putative stocks. In general, however, a resident spawning population of cod occupies eastern Georges Bank (Figure 50), with the exchange of cod between Georges Bank and Browns Bank being much stronger than between Georges Bank and the Great South Channel-Nantucket Shoal (Wang et al., 2009). Based on research survey result, most of the cod on eastern Georges Bank concentrate on the northeastern part.

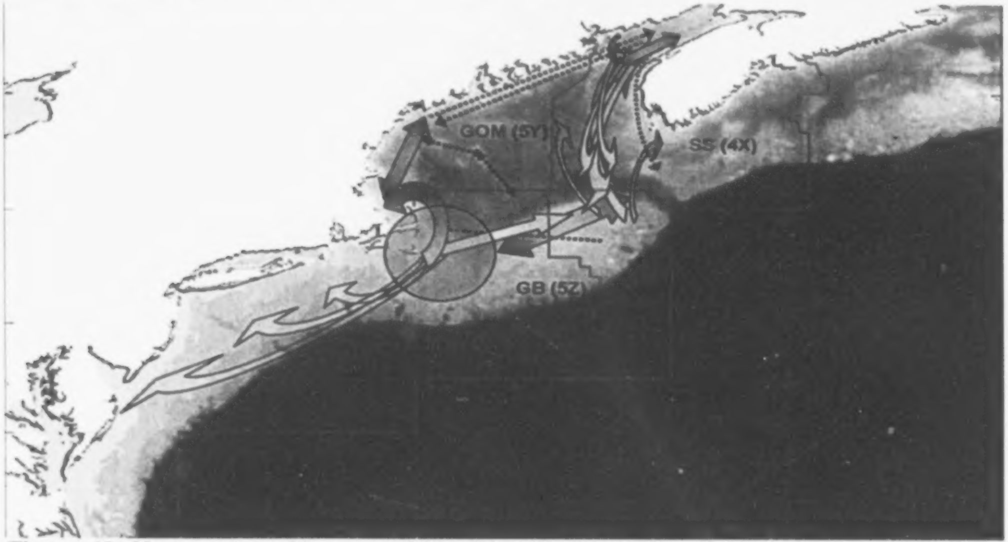

GOM (5Y)
SS (4X)
GB (5Z)

Figure 49. Movement corridors as indicated by the raw tagging data of Atlantic cod from the Northeast Regional Cod Tagging Program for the period 2003-2008 (O'Brien and Worcester, 2009). Note the arrows only show the direction of fish movement and are not quantitative indicators.

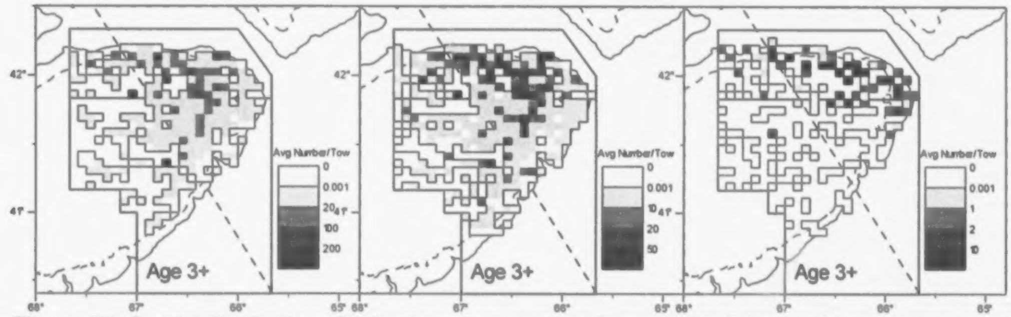

42°
41°
Avg Number/Tow
0
0.001
20
100
200
Age 3+
42°
41°
Avg Number/Tow
0
0.001
10
20
50
Age 3+
42°
41°
Avg Number/Tow
0
0.001
1
2
10
Age 3+
68°
67°
66°
65°

Figure 50. *Spatial distribution of Atlantic cod on eastern Georges Bank from a 10 year average of 1999-2008 DFO survey data (left), NOAA spring survey (middle), and NOAA fall survey (right).*

Life History, Location, and Timing

The most intense spawning activity of eastern Georges Bank cod occurs on the Northeast Peak of the Bank from February to March (Figure 51). Spawning occurs over the remainder of the Bank from October to May (Page et al., 1998; Page et al., 2001). Eggs are pelagic and drift for 2-3 weeks before hatching. The larvae are also pelagic until they reach 4-6 cm in size in approximately 3 months, after which they descend to the bottom (Lough, 2004). Cod eggs and larvae have been noted to drift 2-7 km per day in the gyre on Georges Bank (Lough et al., 1989). By the end of their first year, juvenile cod reach a mean length of 26 cm (Penttila and Gifford, 1976).

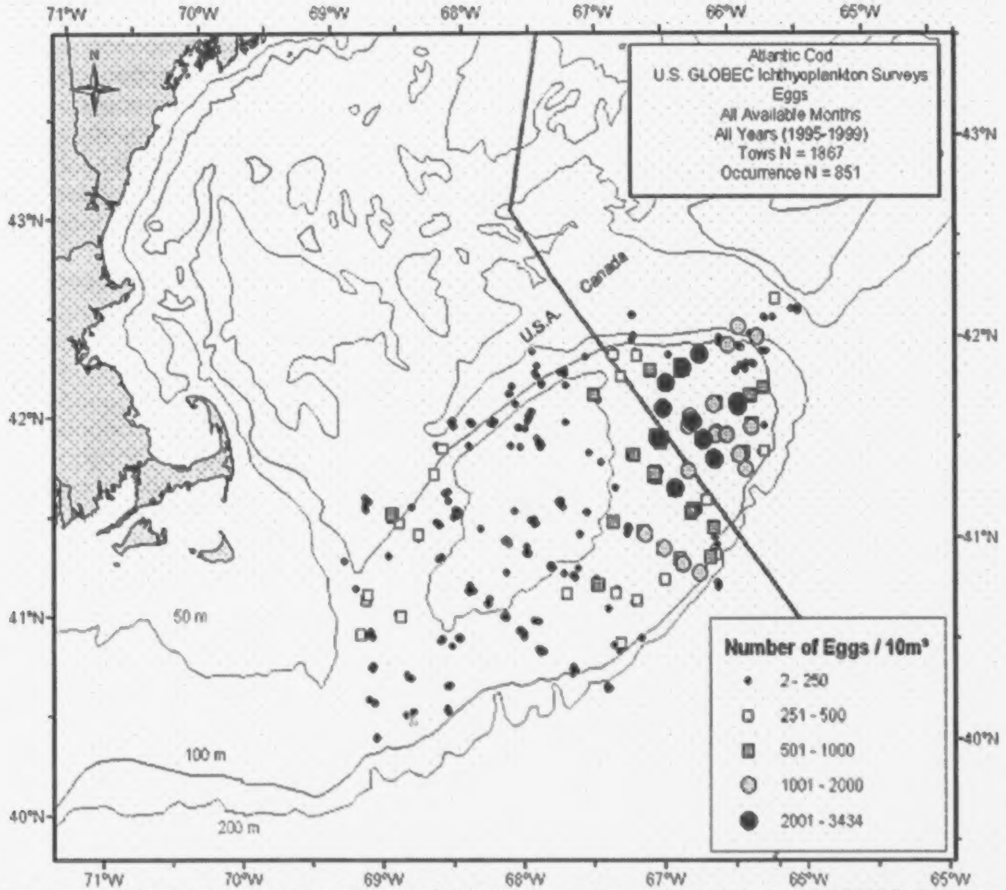

Atlantic Cod
U.S. GLOBEC Ichthyoplankton Surveys
Eggs
All Available Months
All Years (1995-1999)
Tows N = 1867
Occurrence N = 851
Number of Eggs / 10m³
2 - 250
251 - 500
501 - 1000
1001 - 2000
2001 - 3434
U.S.A.
Canada
N
50 m
100 m
200 m
71°W
70°W
69°W
68°W
67°W
66°W
65°W
43°N
42°N
41°N
40°N

Figure 51. Distribution and abundance of Atlantic cod eggs collected during GLOBEC Georges Bank ichthyoplankton surveys for all available years (February-July, 1995 and January-June, 1996-1999) (Lough, 2004).

Known Vulnerabilities

Cod have a swim bladder that is vulnerable to extreme changes in pressure. Both sexes of cod can produce sound with drumming muscles surrounding their swim bladders (Finstad and Nordeide, 2004) and cod have been observed to vocalize during reproductive activity (Fudge and Rose, 2009) in the range of approximately 30-250 Hz (Nordeide and Kjellsby, 1999). Studies have shown that cod have elaborate courtship behaviour (Brawn, 1961; Rowe and Hutchings, 2006).

Status Designation

Cod on eastern Georges Bank is co-managed by Canada and the U.S., since it is a transboundary resource. With the decline of fish population abundance and lower total allowable catch (TAC) since mid-1990s, most of the fish have been captured as bycatch from commercial fisheries on the northeast part of Georges Bank (Figure 52). Atlantic cod is not listed pursuant to SARA. The southern Canada designable unit of Atlantic cod, which includes eastern Georges Bank cod, was assessed as 'endangered' by COSEWIC in April 2010.

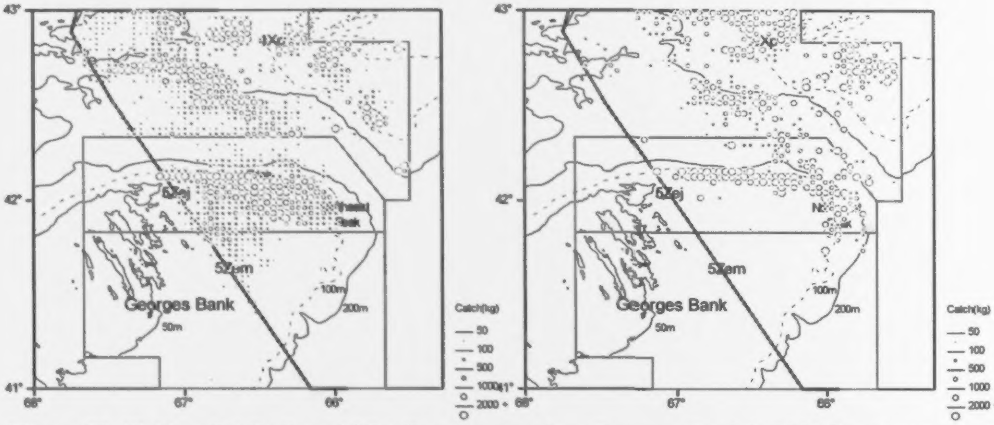
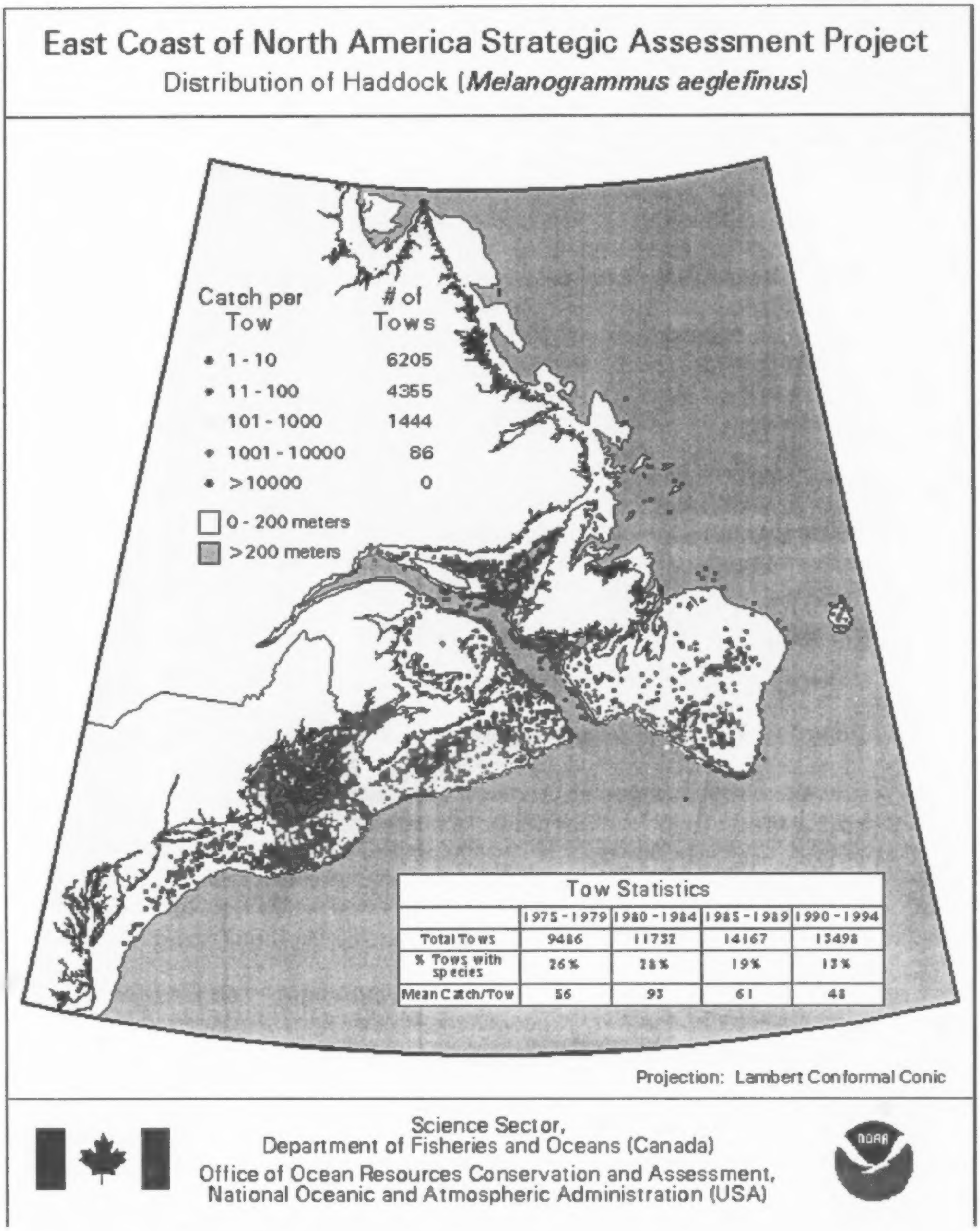


***Figure 52.** Fishing distribution of Atlantic cod on eastern Georges Bank in 2008 from bottom trawl (left) and longline (right) fisheries.*

9.5 HADDOCK

Distribution, Habitat, Abundance, and Predator and Prey

Haddock, *Melanogrammus aeglefinus,* is a bottom dwelling gadoid fish species. It is found on both sides of the North Atlantic Ocean. In the western Atlantic Ocean, haddock can be found from Greenland to Cape Hatteras, North Carolina (Figure 53). Adults range in size from 30 cm to 1 meter in length and can live to over 16 years. A major spawning concentration of haddock resides on eastern Georges Bank. Eastern Georges Bank haddock are typically found on the Bank at water depths of 45-240 m. Haddock generally live in deeper waters than cod and are most common at temperatures of 2-10 °C. Adult haddock appear relatively sedentary, although seasonal migrations occur during periods of spawning activity. Haddock are more closely associated with the bottom than cod, preferring broken ground, gravel, pebbles, clay, smooth hard sand, sticky sand of gritty consistency, and where there are broken shells (Klein-MacPhee 2002).


East Coast of North America Strategic Assessment Project
Distribution of Haddock (*Melanogrammus aeglefinus*)
Catch per Tow
# of Tows
1 - 10 6205
11 - 100 4355
101 - 1000 1444
1001 - 10000 86
>10000 0
0 - 200 meters
>200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	26%	28%	19%	13%
Mean Catch/Tow	56	93	61	48

Figure 53. *Distribution of haddock in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Pelagic larvae and small juveniles feed on phytoplankton, copepods, and invertebrate eggs in the upper part of the water column. Juveniles eat small crustaceans, primarily copepods and euphausiids, as well as polychaetes, and small fishes. Their diet changes to primarily benthic prey when they assume a demersal existence between 3-5 months of age. Demersal haddock feed primarily on small benthic invertebrates, such as crustaceans, mollusks, echinoderms, and worms, as well as some fishes. Their diet becomes more varied as they increase in size.

Eastern Georges Bank haddock adult biomass (ages 3+) increased from 9100 in 1993 to 81,800 t in 2003, declined to 57,800 t in 2005, and subsequently tripled to a record-high 155,600 t in 2009 due primarily to the exceptional 2003 year-class (Figure 54). With expanded age structure, broad spatial distribution, and improved recruitment, current resource productivity is high, hindered only by recent reductions in fish weights at age (TRAC, 2009c).

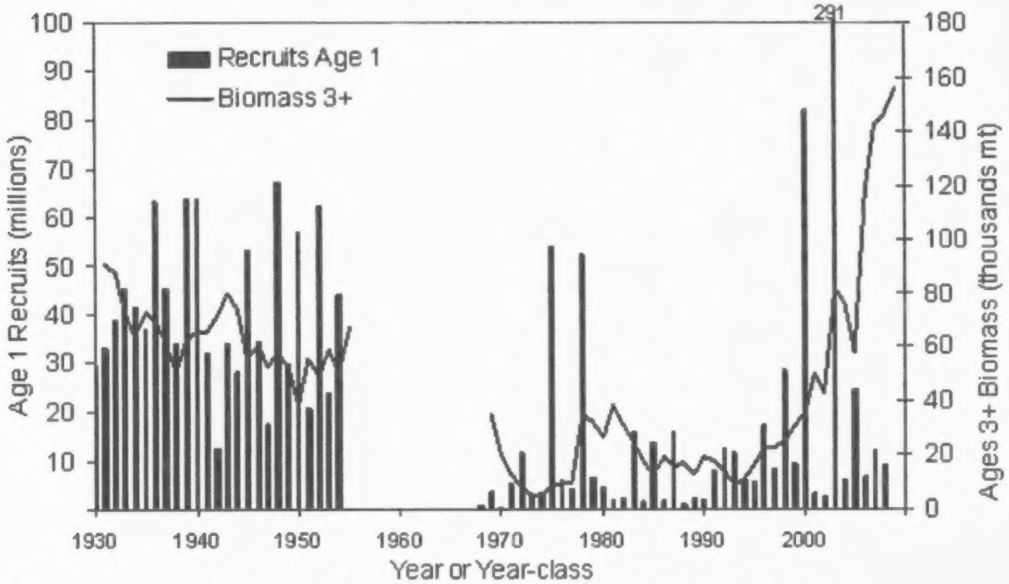


Figure 54. *Biomass (line) and recruitment (bars) of eastern Georges Bank haddock.*

Population Structure Relative to Moratorium Area

Studies have shown a net southwest migration of haddock towards shallower water depths of the central eastern Georges Bank plateau during winter to prepare for springtime spawning, and a net northeast migration towards deeper slopes where they reside during the summer and fall (Van Eeckhaute et al., 1999) when shallower water temperatures are too warm. Age 0 haddock are widely dispersed over the eastern Georges Bank area in fall but, by spring, are more concentrated on the northeast peak and southern flank at age 1 (Figure 55). In spring, haddock at ages 3 and older are broadly distributed between shallower waters of central Georges Bank towards the Northeast Peak and northern edge of the bank. This is the primary spawning area for eastern Georges Bank haddock. Adult haddock spread further west during March to April and are found throughout the eastern Georges Bank area at that time. In February, they are more aggregated on the northern part of the Bank and an area of concentration near the middle of the bank is also observed. Age 2 haddock show a similar distribution to the adults.

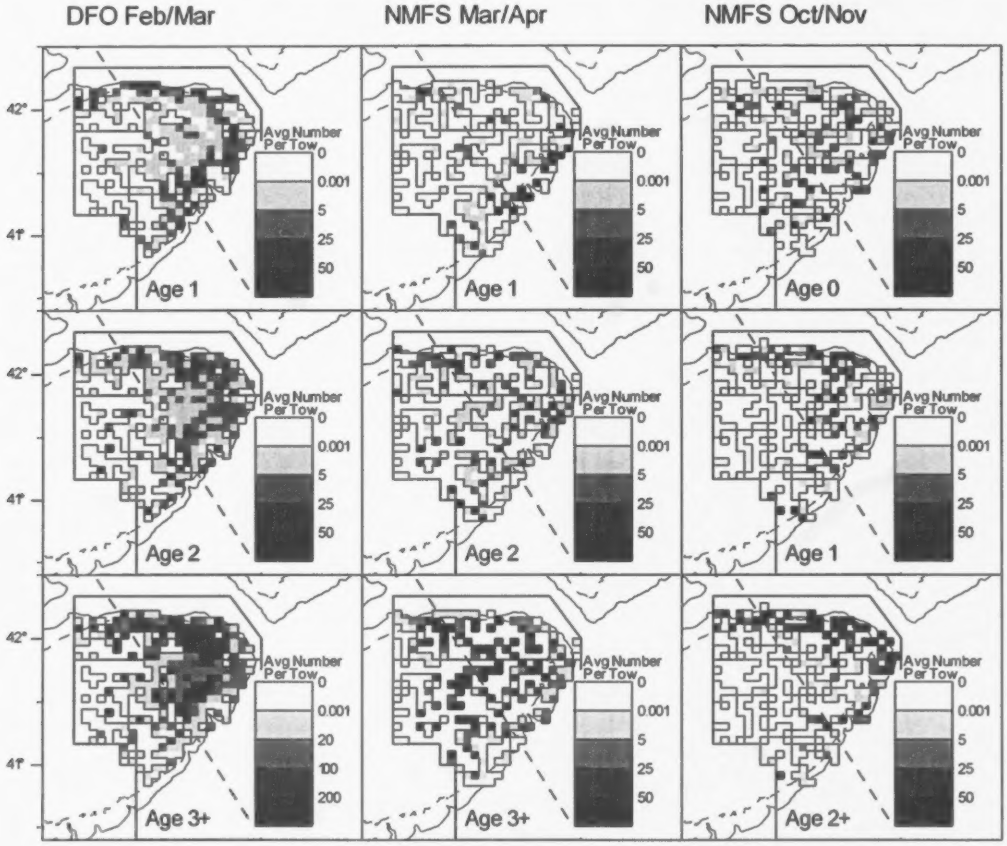


__Figure 55.__ Average distribution of haddock by age group from 1999-2008 in the eastern Georges Bank management area as observed from the DFO February/ March survey and the NOAA March/April and October/November surveys.

Life History, Location, and Timing

Haddock are broadcast spawners that spawn batches of eggs over a time span of several weeks. Females produce from 12,000-3,000,000 eggs per fish. Haddock eggs are buoyant and are concentrated in the upper part of the water column. Incubation times vary with temperature and, at water temperatures typically found on Georges Bank, eggs hatch in about 15 days but can range between 6-42 days at temperature extremes. The larval period is roughly 30-42 days. Juveniles remain in the upper part of the water column for 3-5 months, after which they settle on the bottom when suitable habitat is found (Brodziak, 2005). Larvae and pelagic juveniles are concentrated in a limited depth stratum defined by the thermocline, which is usually between 10-40 m (Klein-MacPhee, 2002). Their prey organisms are concentrated above the thermocline, providing an abundant food source. Small haddock (i.e. 60-70 mm in length) have been found to associate with jellyfish, which results in their movement being controlled in part by the drift of jellyfish.

Surveys of haddock eggs, which occur at stage 3 or later, allow for the differentiation with cod eggs and provide the spatial extent of the spawning area. The majority of spawning activity occurs between early- to mid-March and mid- to late- April (Page et al., 1998), but eggs were found from January to July as observed by MARMAP (Figure 56) and GLOBEC (Figure 57). Haddock egg distributions indicate the presence of eggs throughout most of the fishery statistical units on Georges Bank, in water depths less than 100 m. Presence of haddock eggs, however, are most prevalent on the eastern portion of the Bank (Figure 57). As larvae develop, they are re-distributed between the Northeast Peak and southern edge of the Bank, consistent with mean circulation patterns in the region (Van Eeckhaute et al., 1999).

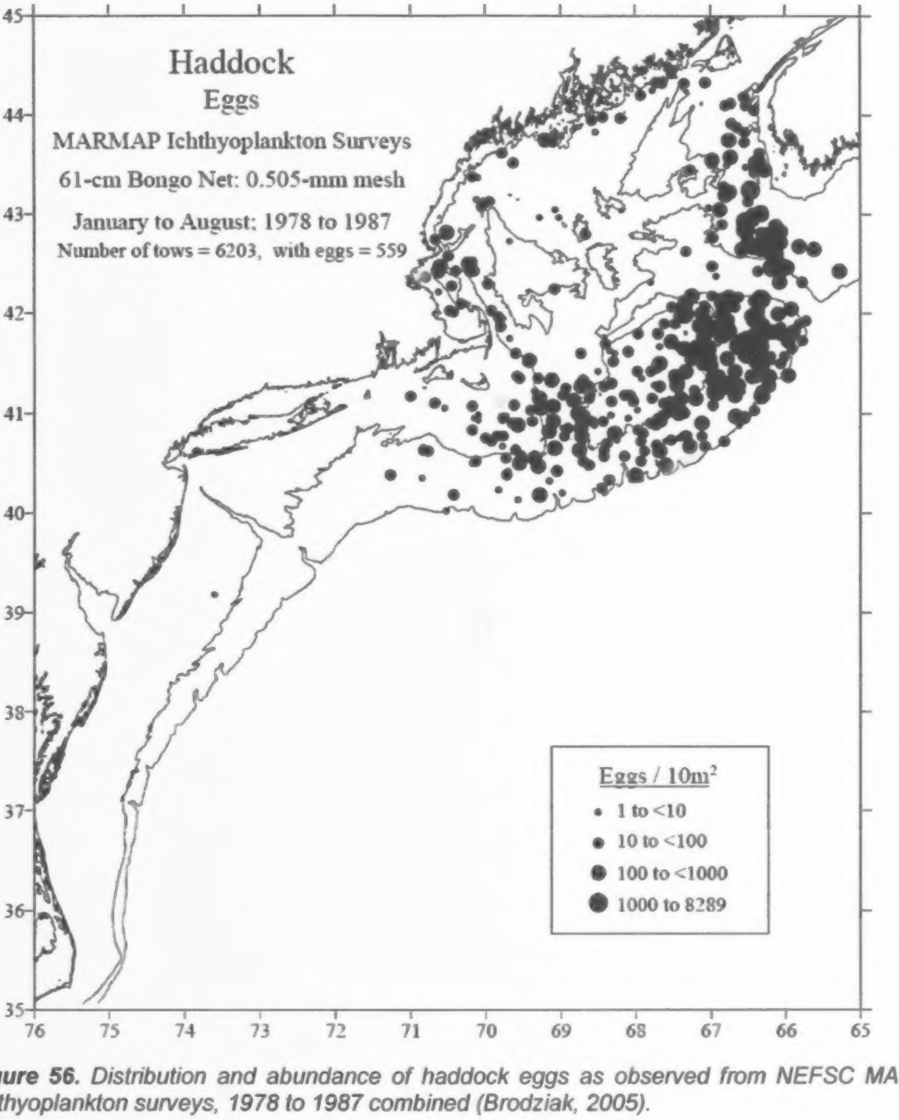

Haddock
Eggs
MARMAP Ichthyoplankton Surveys
61-cm Bongo Net: 0.505-mm mesh
January to August: 1978 to 1987
Number of tows = 6203, with eggs = 559
Eggs / 10m²
1 to <10
10 to <100
100 to <1000
1000 to 8289
45
44
43
42
41
40
39
38
37
36
35
76
75
74
73
72
71
70
69
68
67
66
65

Figure 56. Distribution and abundance of haddock eggs as observed from NEFSC MARMAP ichthyoplankton surveys, 1978 to 1987 combined (Brodziak, 2005).

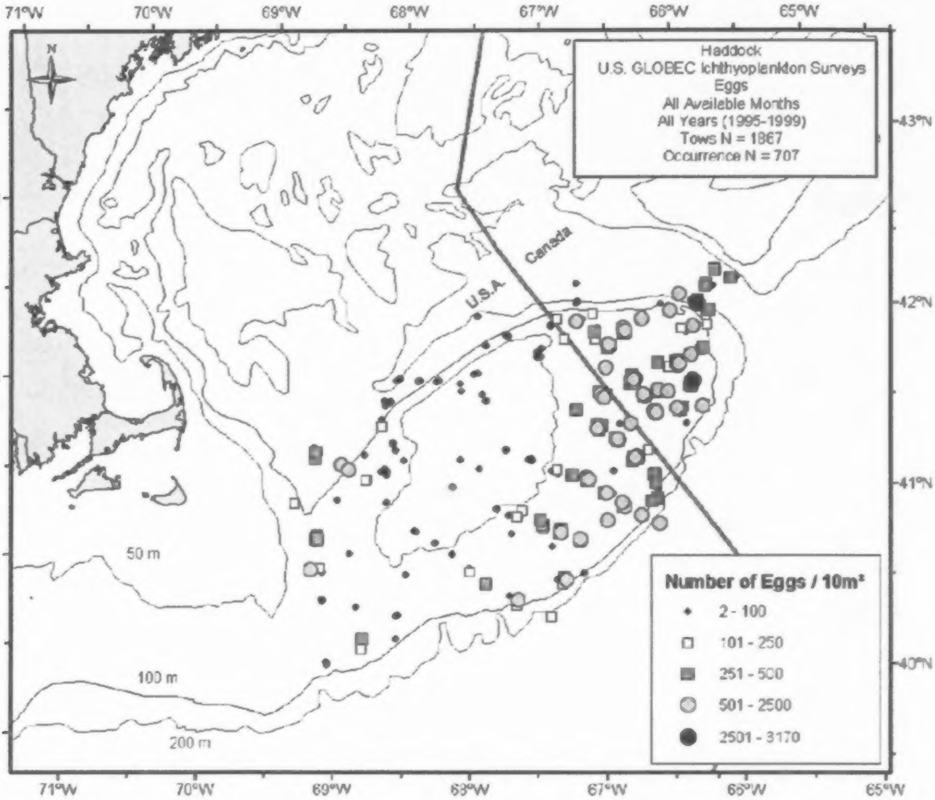

Haddock
U.S. GLOBEC Ichthyoplankton Surveys
Eggs
All Available Months
All Years (1995-1999)
Tows N = 1867
Occurrence N = 707
Number of Eggs / 10m²
2 - 100
101 - 250
251 - 500
501 - 2500
2501 - 3170
U.S.A.
Canada
50 m
100 m
200 m
N
71°W
70°W
69°W
68°W
67°W
66°W
65°W
43°N
42°N
41°N
40°N

Figure 57. Distribution and abundance of haddock eggs as observed from GLOBEC ichthyoplankton surveys, February to July, 1995 and January to June, 1996-1999, combined (Brodziak, 2005).

The GLOBEC program demonstrated that the highest numbers of larvae were in March and April and mostly in southern areas of the Bank between the 50-100 m isobaths. Haddock begin to settle to the bottom by about July and August. As they age to 2 years, they start concentrating on the northern edge and Northeast Peak. By age 2, they begin to display the seasonal migration associated with spawning, which is evident for adult haddock. Very large year-classes are widespread throughout the stock area, both as juveniles and adults, as was observed for the 1963 and, more recently, the 2003 year-class. Many haddock mature by age 2, although it is uncertain whether these fish spawn successfully. By age 3, eastern Georges Bank haddock are considered to be mature.

Known Vulnerabilities

Haddock have a swim bladder that is vulnerable to extreme changes in pressure. Both male and female haddock can produce a range of sounds (Hawkins et al., 1967; Hawkins and Rasmussen, 1978; Hawkins, 1986), and their sounds have been observed during spawning activity. Male haddock produce sounds that vary in their characteristics as courtship proceeds (Hawkins et al., 1967; Hawkins, 1986; Hawkins and Amorim, 2000). Since juvenile and adult haddock are closely associated with the bottom and their prey species are generally bottom dwellers, living in or on the substrate, any contamination of the substrate by pollutants has the potential to affect the haddock directly through exposure to the pollutants or indirectly by ingestion of prey items that have been exposed to pollutants. All life stages would be vulnerable to pollutants dispersed in the water column.

Status Designation

Eastern Georges Bank haddock is not listed pursuant to SARA and has not been evaluated by COSEWIC.

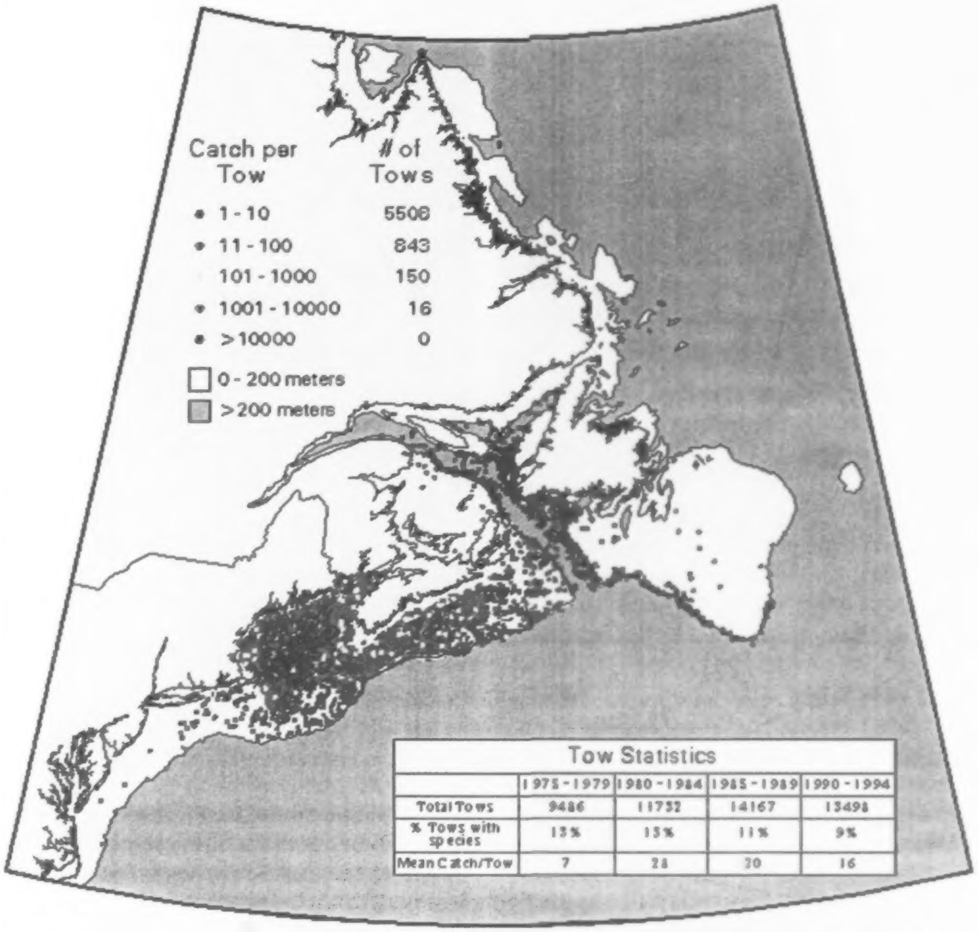
9.6 POLLOCK

Distribution, Habitat, Abundance, and Predator and Prey

Pollock, *Pollachius virens,* is a gadoid fish species that is found on both sides of the North Atlantic. In the western North Atlantic, it ranges from southern Labrador to Cape Hatteras, with major concentrations on Georges Bank, in the Gulf of Maine, and on the Scotian Shelf (Figure 58). Pollock are found at depths ranging from the surface to 380 m depth and at bottom temperatures varying from 5-8° C (Scott, 1982). Offshore pollock aggregations are often associated with hard bottom topographic features, such as rises, ridges, or mounts, but they are generally unselective of bottom type and can be associated with sediments ranging from gravel to clay (Scott, 1982).

East Coast of North America Strategic Assessment Project

Distribution of Pollock (*Pollachius virens*)


Catch per Tow
# of Tows
1 - 10 5506
11 - 100 843
101 - 1000 150
1001 - 10000 16
>10000 0
0 - 200 meters
>200 meters
Projection: Lambert Conformal Conic

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11752	14167	13498
% Tows with species	13%	13%	11%	9%
Mean Catch/Tow	7	28	20	16

Figure 58. *Distribution of pollock in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Juvenile pollock feed on crustaceans, especially small euphausiids and amphipods, although small fishes including herring and sand lance are also consumed. Food of adult pollock includes euphausiids, squid, and fish such as herring, sand lance, and silver hake (DFO, 2009c). The diet of pollock from the Scotian Shelf and Bay of Fundy has shown decadal changes, with euphausiids (krill) being the predominant prey in the 1960s and 1980s, less so in the 1990s, but has been predominant again since 2003 (Carruthers et al., 2005).

Estimates of age 4+ (considered spawning stock) biomass declined from approximately 66,000 t in 1984 to approximately 7500 t in 2000. Biomass has been rebuilding since

2000, increasing steadily to about 29,000 t in 2007 then declining to 27,000 t in 2008 (Figure 59). Concerning recruitment, the 2001 year-class was estimated to be the strongest at age 2 since the 1988 year-class, and the third highest in the time series. Early indications for the 2004 and 2005 year-classes are that they are the lowest in the time series, while the 2002 and 2003 year-classes are about average. Over the past decade, pollock biomass has been recovering such that catches of pollock from the Canadian portion of Georges Bank have represented about 20% of total landings (average = 1100 t for 2000-2009) (Stone et al., 2009).

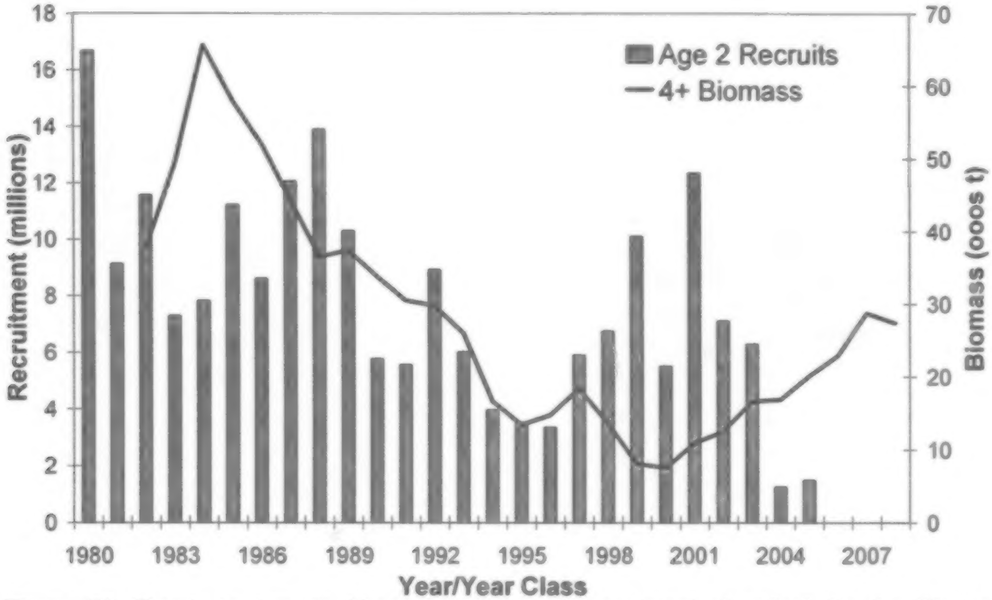


Figure 59. *Trends in Age 4+ biomass and Age 2 recruitment of pollock for the Western Component population (DFO, 2009c).*

Population Structure Relative to Moratorium Area

A detailed evaluation of stock structure in 2003 indicated that the current Maritimes management unit for pollock (NAFO Divisions 4VWX+5) is represented by two population components: a slower-growing Eastern Component (4VW+4Xmn) and a faster-growing Western Component (4Xopqrs+5) (Neilson et al., 2003). For management purposes, the southernmost limit of the Western Component is considered to include fish in the Canadian part of Georges Bank and the eastern Gulf of Maine. Tagging studies suggest considerable movement of pollock between the Scotian Shelf and Georges Bank, but less between the Scotian Shelf and Gulf of Maine (Mayo et al., 1989; Mayo, 1998). A recent evaluation of Canadian tagging data by Neilson et al. (2006) demonstrated that pollock tagged and released in the Bay of Fundy were recaptured on northeastern Georges Bank and in the eastern Gulf of Maine, implying that they are capable of extensive movements. The migratory routes and degree of mixing among these areas have yet to be determined.

Life History, Location, and Timing

The life history of pollock involves an offshore spawning and larval phase, recruitment to the coastal environment for a period of one to two years, followed by an offshore migration. Unlike other cod-like fishes, pollock show strong schooling behaviour and spend more time moving freely through the water column rather than near the bottom. Spawning areas have been identified on the Scotian Shelf, northeastern Georges Bank, and in the western Gulf of Maine. Based on the seasonal distribution of pollock eggs and larvae from Canadian ichthyoplankton surveys, spawning occurs on northeastern Georges Bank during November-December (Neilson and Perley, 1996; Hanke et al., 2001). The U.S. MARMAP icththyoplankton surveys indicate that the highest egg and larval densities occur on the Bank from November through to February (Reid et al., 1999).

Known Vulnerabilities

Pollock produce sounds by means of a multi-lobed swim bladder vibrated by contractions of associated muscles, as well as general body contractions (Fish and Mowbray, 1970). Their hearing range is similar to that of cod, and they may be sensitive to excessive noise levels.

Status Designation

Pollock is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.7 MONKFISH

Distribution, Habitat, Abundance, and Predator and Prey

Monkfish, *Lophius americanus*, also called goosefish or angler, are distributed from the Grand Banks and Northern Gulf of St. Lawrence south to Cape Hatteras, North Carolina (Figure 60). Monkfish are a bottom dwelling species typically found on sand, mud, and shell habitats. Individuals have been collected from inshore areas to depths greater than 800 m, although highest concentrations occur from 70-100 m water depth and in deeper waters of greater than 190 m depth. They have been found at temperatures from 0-24 °C but, in Canadian waters, appear most abundant at water temperatures of 3-9 °C (DFO, 2002a). Monkfish make seasonal onshore-offshore migrations in response to thermal conditions and prey availability. In the Gulf of Maine, monkfish move and stay offshore to avoid cold coastal conditions in the winter-spring and return inshore as coastal waters warm in the summer and fall (Steimle et al., 1999).

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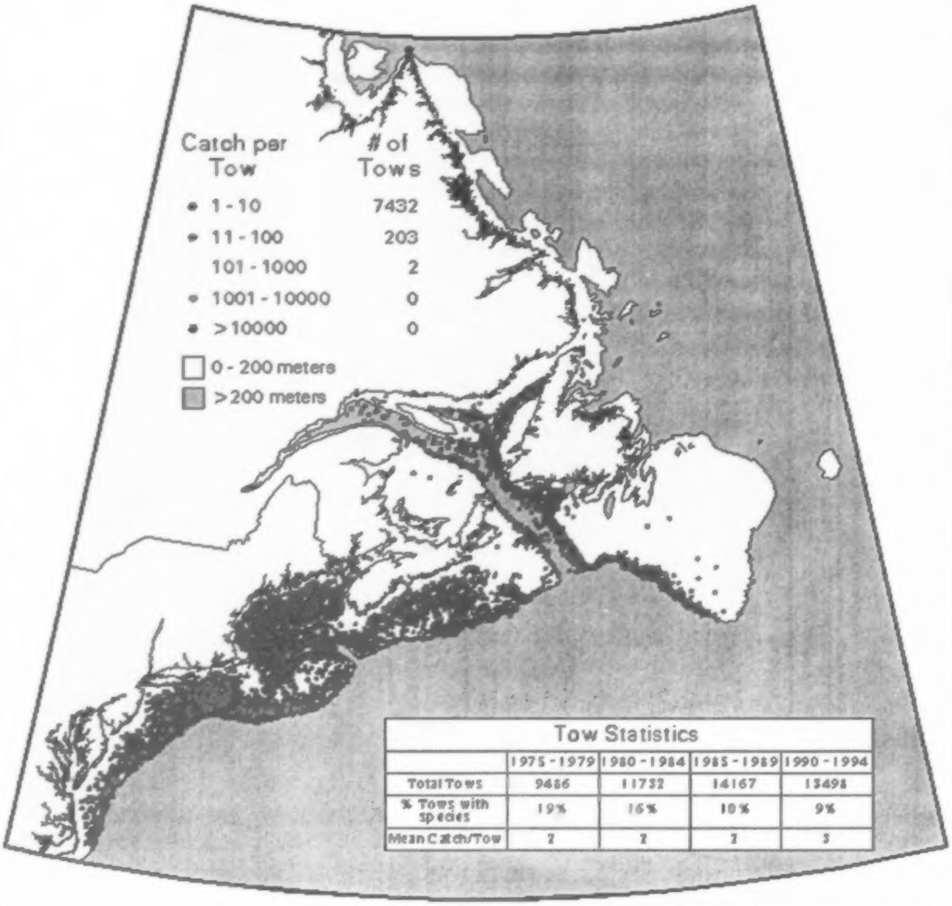
Distribution of Goosefish (Angler) (***Lophius americanus***)



Catch per Tow	# of Tows
● 1 - 10	7432
● 11 - 100	203
101 - 1000	2
● 1001 - 10000	0
● >10000	0

☐ 0 - 200 meters

▨ >200 meters

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	19%	16%	10%	9%
Mean Catch/Tow	2	2	2	3

Projection: Lambert Conformal Conic

Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Figure 60. *Distribution of monkfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Larvae feed on zooplankton, including copepods, crustacean larvae, and chaetognaths. Small juveniles start eating fish, such as sand lance, soon after they settle to the bottom, but invertebrates, especially crustaceans, can make up a large part of the diet. The consumption of invertebrates decreases among larger juveniles. Diets can vary regionally and seasonally depending on what prey is available. Monkfish are opportunistic feeders. The diet of an adult consists primarily of fish, crustaceans, and squid. On occasion, however, they have been known to eat sea birds and diving ducks (Steimle et al., 1999; Johnson et al., 2008).

Based on a 2002 assessment, abundance of adult monkfish in 4X remained at or below the average (approximately 500,000 individuals). The proportion of large fish, greater than 60 cm in length, continued to decline and biomass remained low. There was evidence of improved immature abundance since 1992, particularly in 1995 and 2000. This, however, this did not appear to result in increased biomass (DFO, 2002a). Biomass had shown some increase, but to a lesser degree than abundance, and remained at a low level of approximately 3000 t. Though there is no evidence to suggest a north to south migration pattern, U.S. survey indices in the Gulf of Maine were similar to those on the Scotian Shelf (Beanslands et al., 2000).

Population Structure Relative to Moratorium Area

The stock structure of monkfish is unknown, but U.S. survey distributions suggest northern (i.e. Gulf of Maine and northern Georges Bank) and southern (i.e. southern Georges Bank and Mid-Atlantic Bight) components with shallow waters of Georges Bank as a boundary zone. Canadian survey distributions do not suggest a discontinuity between Scotian Shelf and Georges Bank components of the stock. While onshore-offshore migrations have been reported (Richards et al., 2008), the degree of mixing in both U.S. and Canadian waters remains unknown and large scale migrations have not been reported (DFO, 2002a).

Life History, Location, and Timing

Females appear to grow larger and live longer than males. Females live up to 12 years of age, reaching a size of over 100 cm in length while males have not been found older than 9 at approximately 90 cm in length. Sexual maturity occurs between ages 3 and 4. Spawning occurs from spring through early fall with a peak in May to June. Females lay a non-adhesive, buoyant mucoid veil, although the method of fertilization has not been observed or reported. Eggs hatch in 7-22 days, after which the larvae spend several months in a pelagic phase before settling to the bottom at a size of about 8 cm in length (DFO, 2002a). Spawning locations are not known but are thought to be on inshore shoals to offshore, as egg veils have been found close to shore and in deep water (Richards et al., 2008).

Known Vulnerabilities

Vulnerabilities for monkfish are not known, but are expected to be similar to other demersal fish with buoyant eggs and pelagic larvae.

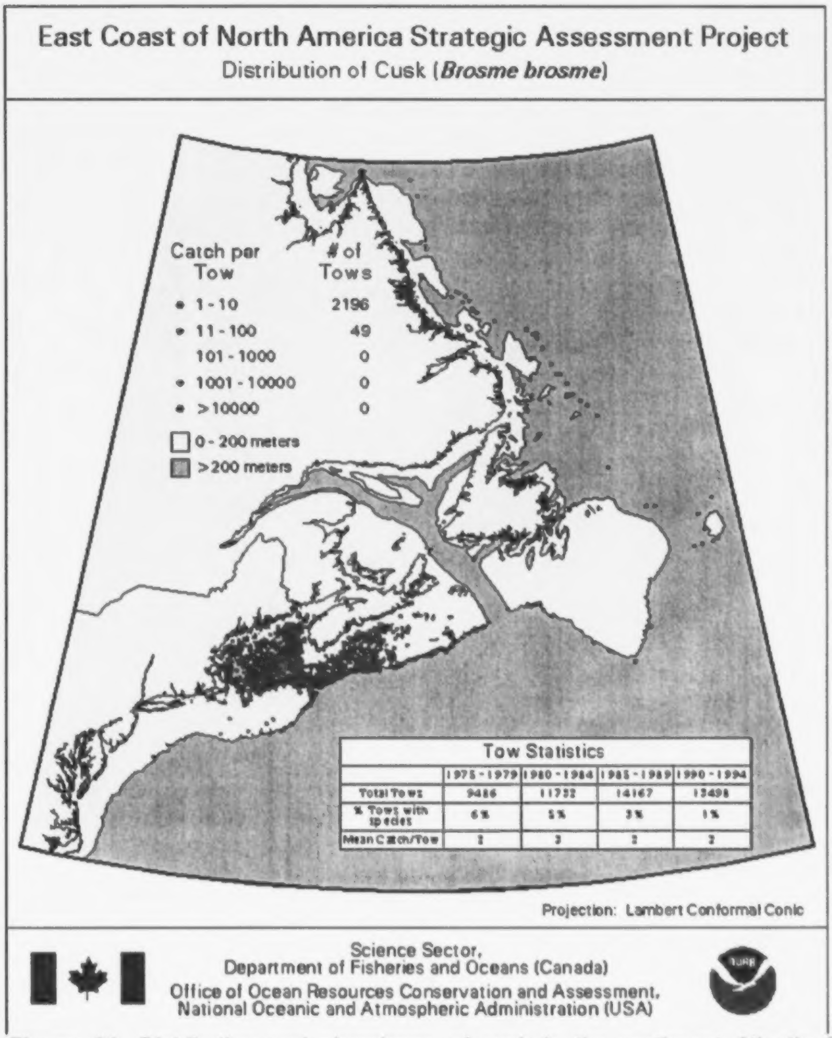
Status Designation

Monkfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.8 CUSK

Distribution, Habitat, Abundance, and Predator and Prey

Cusk, *Brosme brosme*, is a solitary, sedentary, slow swimming fish species. It is distributed across the northern North Atlantic from the United States, north to Greenland, across to Iceland, Svalbard, along the Murmansk Coast, and south in the Northeast Atlantic to Ireland. It has also been found along the mid-Atlantic Ridge (Figure 61). In Canadian waters, cusk is most common in the Gulf of Maine, western Scotian Shelf, and along the edge of the Scotian Shelf to Banquereau Bank. It is rare in the Gulf of St. Lawrence and the inner Bay of Fundy (Harris and Hanke, 2010).


East Coast of North America Strategic Assessment Project
Distribution of Cusk (*Brosme brosme*)
Catch per Tow
# of Tows
• 1-10 2196
• 11-100 49
101-1000 0
• 1001-10000 0
• >10000 0
☐ 0-200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	6%	5%	3%	1%
Mean Catch/Tow	2	3	2	2

Figure 61. Distribution and abundance of cusk in the northwest Atlantic Ocean based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (Brown et al., 1996).

Adult cusk prefer a hard, rocky bottom habitat, including boulders, rocks or pebbles (Oldham, 1972). Cusk is considered a deep-water species, although it has been observed, less commonly, in shallow waters. They prefer relatively warm intermediate depths and are found at temperature from 2-12 °C on the Scotian Shelf and 1-10 °C in the Gulf of Maine (Scott and Scott, 1988). Globally, their depth range is reported to be from 20-1185 m, but is rarely found deeper than 400 m (Oldham, 1966; Hareide and Garnes, 2001). In the Canadian Atlantic, cusk are reported to occur between 150-450 m, however, Harris and Hanke (2010) observed the highest catch rates between 400-600 m with cusk caught at depths as great as 1185 m.

The diet of cusk in the northwest Atlantic is not well known, as their stomachs generally evert when they are brought to the surface. Limited stomach samples, however, have contained invertebrates, crabs, and shrimps. A variety of fish species have also been found in cusk stomachs. On occasion, cusk have been found in the diets of cod and halibut (Harris et al., 2002). Cusk abundance has declined since the 1970s, although there is insufficient data to determine the degree of decline and there is conflicting evidence on whether cusk abundance has continued to decline since the late 1990s (DFO, 2008c). Based on Halibut Industry survey data, this decline has stabilized (Harris and Hanke, 2010). It is unlikely that this conflict will be resolved in the near future. A by-catch cap of 1000 t for NAFO Divisions 4VWX was first implemented in 1999 (Figure 62). In 2003, this cap was reduced to 750 t for 4VWX+5 where it has remained since. The effectiveness of this measure for mitigation is unknown since the exploitation rate is unknown. The ability to detect future trends in abundance is limited by current monitoring programs (DFO, 2008c).

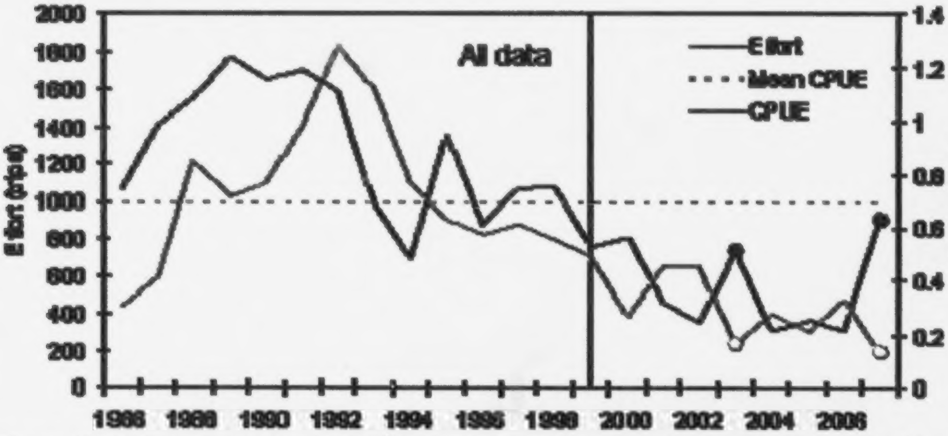


Figure 62. *Catch per unit effort (t trip^{-1}) of cusk by quota year in the longline fishery in 4Xnopqu, captured by vessels in tonnage classes 2 and 3. The dashed line represents the long-term mean. Due to cusk closures to longliners, 2003 is only represented by April-November and 2007 is only represented from April-September (indicated by dots). A bycatch cap of 1000 t for longliners in 4VWX was first implemented in 1999 (indicated by vertical line). It reduced to 750 t for longliners in 4VWX+5 in 2003 where it continues to remain.*

Population Structure Relative to Moratorium Area

Cusk are thought to be sedentary. At present, there is no evidence to suggest that there are distinct populations of cusk in Atlantic Canada (DFO, 2008c). Around Georges Bank, the areas of highest catches are in the deeper waters in the Northeast Channel and off the Northeast Peak, as well as in the Fundian Channel. Catches on Georges Bank itself are lower, but do occur (Harris and Hanke, 2010). Cusk on banks are known to be smaller on average than those found in deeper waters (Oldham, 1966).

Life History, Location, and Timing

Cusk spawn between March and July in the Northeast Atlantic (Magnusson et al., 1997). On the Scotian Shelf, spawning occurs from May to August and peaks in June (Oldham, 1972; Collette and Klein-MacPhee, 2002), however, cusk in spawning condition have been observed as early as March on the western Scotian Shelf and Gulf of Maine. Cusk are among the most fecund of fishes with greater than 1 million eggs in mature fish greater than 60 cm in length (Oldham, 1966). Cusk eggs are buoyant and hatch 4 mm larvae. Larvae remain in the upper water column and settle to the bottom at approximately 50 mm in length (Harris and Hanke, 2010).

On the Scotian Shelf, 50% of male and female cusks reach maturity at 5 and 7 years, respectively. Consequently, the average age of maturity on the Scotian Shelf is 6 years. Length at 50% maturity was reported to be 43.5 cm for males and 50.7 cm for females. There is no significant difference in growth rates between the sexes, although males mature more quickly (Oldham, 1966; Oldham, 1972). The otoliths of larger fish are very difficult to read. The oldest fish was aged at approximately 20 years (Magnusson et al., 1997). Recently, radiocarbon dating methods have been used to age cusk from Canadian waters and have resulted in older age estimates. This data suggests that cusk may reach maturity at 10 years, in contrast to previous estimates of 5-6 years (Oldham, 1966).

Known Vulnerabilities

Cusk has been found to be highly vocal. Sound recordings were only done during aggressive behaviour and consisted of a long series of low frequency, short pulses repeated at short intervals (Soldal et al., 2000). The only known major source of human-induced mortality is fishing mortality.

Status Designation

Cusk is under consideration for addition to Schedule 1 of SARA. In 2003, COSEWIC assessed cusk as 'threatened' (COSEWIC, 2003a), which was reconfirmed 2006.

9.9 REDFISH

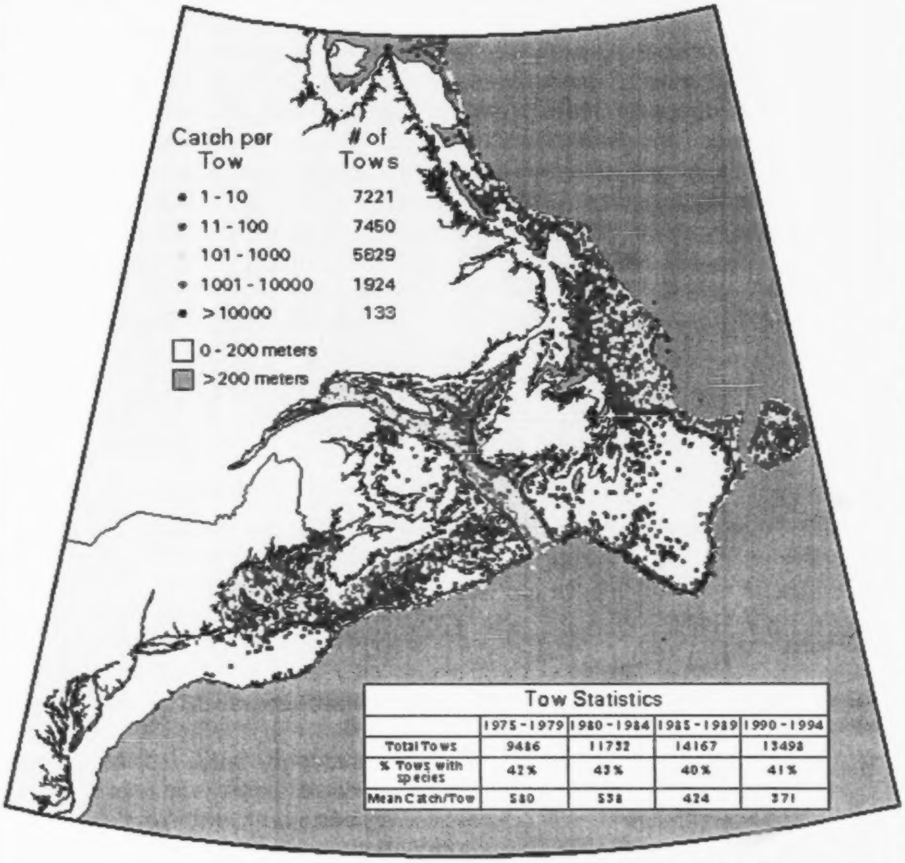
Distribution, Habitat, Abundance, and Predator and Prey

Three species of redfish are present in the northwest Atlantic (*Sebastes mentella*, *S. fasciatus*, and *S. marinus* [=*S. norvegicus*]). These three species are similar and nearly impossible to distinguish by their appearance. They are not separated in the fishery and are managed together, although they have different depth preferences and distributions (DFO, 2000; Breeze et al., 2002). Redfish, also known as ocean perch, are a semi-pelagic species occurring on both the Atlantic Ocean in cool waters (i.e. 3-8 °C) along the slopes of banks and deep channels in the depths of 100-700m over rocky, mud, or clay-silt bottom (Scott and Scott, 1988; COSEWIC, 2010). In the Northwest Atlantic, redfish range from Baffin Island in the north to waters off the Gulf of Maine in the south

(COSEWIC, 2010) (Figure 63). Redfish are common in the Gulf of Maine, in the deeper waters north and west of Georges Bank and, to a lesser extent, on Browns Bank and the continental slope (Pikanowski et al., 1999).

East Coast of North America Strategic Assessment Project

Distribution of Redfishes (created) (***Sebastes spp.***)



Tow Statistics				
	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	42%	43%	40%	41%
Mean Catch/Tow	580	538	424	371

Projection: Lambert Conformal Conic

Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Figure 63. *Distribution of redfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Except for the area of the Flemish Cap, *S. marinus* is relatively uncommon. *S. fasciatus*, occurring in the deep basins and along the edge of the continental shelf, range predominantly from the southern Grand Banks to the Gulf of Maine where it predominates on Georges Bank and in the Bay of Fundy-Gulf of Maine waters (Figure 63). In the deeper waters off the continental shelf and slope, *S. mentella* range predominately from the Gulf of St. Lawrence northward. *S. mentella* ranges farther north, goes further offshore and into deeper water than *S. fasciatus* and *S. marinus*. The distribution of *S. fasciatus* and *S. mentella* in the Northwest Atlantic follow a north-south gradient with *S. mentella* more abundant in the north of the range whereas *S. fasciatus* are more prevalent in the south (COSEWIC, 2010). The range of both species overlaps in the Laurentian Channel and on the eastern Scotian Shelf and slope (Scott and Scott, 1988; DFO, 2000).

Redfish larvae are released soon after the spring plankton bloom and through the summer production of zooplankton in the Gulf of Maine. They feed on copepod, euphausiids, and fish and invertebrate eggs. Juvenile and adult redfish eat euphausiids, mysids, and fish. They feed most actively at night when they rise off the bottom following the vertical migration of their prey. Fish become increasingly important food as redfish increase in size (Pikanowski et al., 1999). Estimates of population biomass in the management unit, although highly-variable between years, demonstrate no trend over time. With the decline of other groundfish stocks in the early 1990s, fishing pressure on redfish has increased (DFO, 2002b).

Stock and spawning biomass are also increasing. Nonetheless, the spawning stock is currently still at a low level compared to the earlier period in the time series. The Scotian Shelf population (Unit 3) is considered stable, with the average biomass index through the 1990s and early 2000s at only about 7% of what it was in the 1980s. Redfish assessments in Unit 3 (4X and 4W) indicate stability in the population biomass and improved recruitment. This has resulted in an increase in the population biomass to levels greater than that seen during the survey time series (Clark et al., 2010). The U.S. surveys of the Gulf of Maine and Georges Bank region indicate that the biomass of redfish appears to have increased during the early 2000s. Spawning stock biomass in the region increased from 124,000 t in 2001 to 175,800 t in 2004 (Mayo et al., 2007).

Population Structure Relative to Moratorium Area

The stocks consist of a mixture of *S. fasciatus*, which is the predominant species occurring in deep basins and waters along the continental shelf and *S. mentella*, occurring in deep water basins and deeper portions of the continental slope (COSEWIC, 2010). Research indicates that redfish located on the Scotian Shelf belong to a separate stock of *S. fasciatus* from the Gulf of St. Lawrence and Laurentian Channel. There is an indication of a genetic separation between Scotian Shelf and Gulf of Maine populations (DFO, 2002b). Questions remain concerning stock structure and mixing in the Gulf of St. Lawrence and Laurentian Channel, however, there is little evidence for a seasonal change in distribution of redfish on the Scotian Shelf. If redfish make migrations, it is believed that they are less than 100 km in distance (Pikanowski et al., 1999). It is believed that redfish movements are limited, alhtough given their long life span, adults could undertake major long term movements (COSEWIC, 2010).

Life History, Location, and Timing

Redfish are slow-growing, long-lived, and characterized by a low natural mortality rate. Reports have estimated that sexual maturity is reached at 5.5 years (O'Brien et al., 1993) with longevity of up to 75 years (COSEWIC, 2010). Little is known about redfish breeding, but fertilization is internal and fecundity is low. Breeding is thought to occur in the fall from September to December, but fertilization is delayed until February to April.

Larvae are released throughout the range of the adults in mid-water from April to August, with a peak in late-May to early-June (Mayo et al., 2007; COSEWIC, 2010). The young are pelagic until they reach approximately 25 mm in size, at which time they move to the ocean floor (Scott and Scott, 1988; COSEWIC, 2010).

Known Vulnerabilities

The life history characteristics of redfish, including late maturity and low fecundity, render this species vulnerable to human impacts.

Status Designation

Redfish is not listed pursuant to SARA, although COSEWIC designated redfish as 'threatened' in April 2010.

9.10 WOLFISH

Wolffish are a small family of marine fish which inhabit waters of moderate depth in the North Atlantic and North Pacific oceans. Three species occupy the waters of Atlantic Canada, however, the species found most commonly on Georges Bank is the Atlantic wolffish. The northern wolffish, *Anarhichas denticulatus,* occurs mainly in the arctic portions of the North Atlantic. In Canadian waters, it is found from the arctic in the north to the eastern Scotian Shelf in the south (Scott and Scott, 1988). The DFO groundfish surveys on the Scotian Shelf have collected very few individuals, all of which were located in NAFO Division 4V (Figure 64).

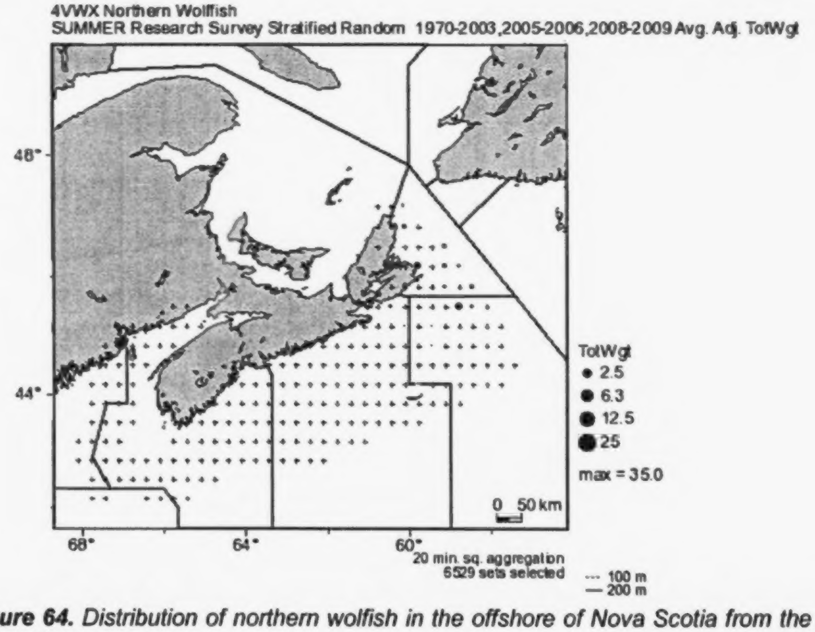

4VWX Northern Wolffish
SUMMER Research Survey Stratified Random 1970-2003,2005-2006,2008-2009 Avg. Adj. TotWgt
48°
44°
68°
64°
60°
0 50 km
TotWgt
● 2.5
● 6.3
● 12.5
● 25
max = 35.0
20 min. sq. aggregation
6529 sets selected
--- 100 m
— 200 m

Figure 64. *Distribution of northern wolfish in the offshore of Nova Scotia from the DFO summer research vessel survey.*

The spotted wolffish, *Anarhichas minor*, in the western Atlantic occur from west Greenland, the Grand Banks, and the eastern Scotian Shelf (Scott and Scott, 1988).

The DFO groundfish surveys conducted since 1970 have encountered few individuals on the Scotian Shelf with all occurrences coming from 4V (Figure 65).

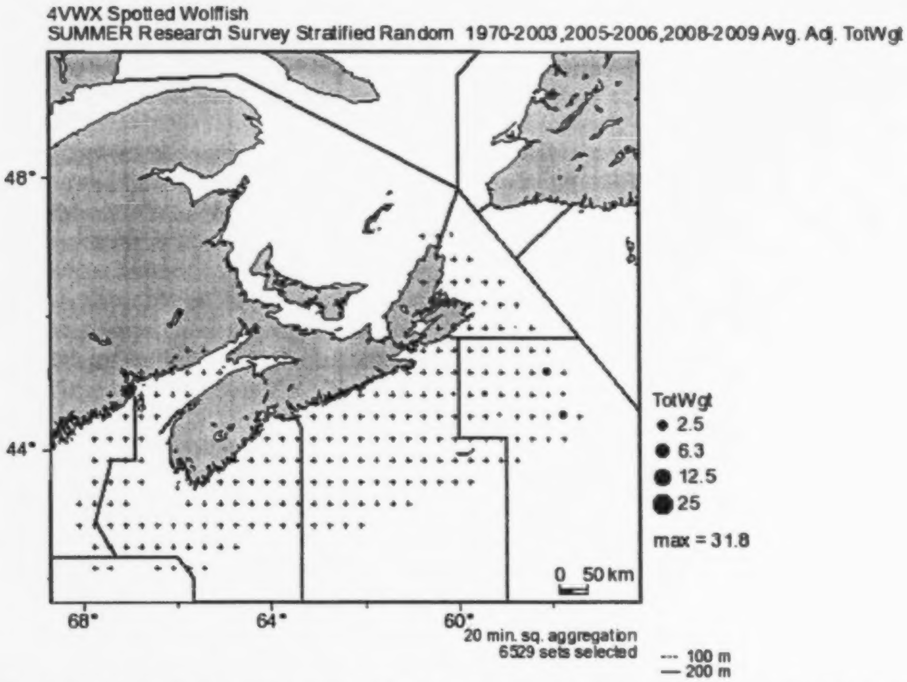

4VWX Spotted Wolffish
SUMMER Research Survey Stratified Random 1970-2003,2005-2006,2008-2009 Avg. Adj. TotWgt
48°
44°
68°
64°
60°
0 50 km
TotWgt
● 2.5
● 6.3
● 12.5
● 25
max = 31.8
20 min. sq. aggregation
6529 sets selected
--- 100 m
— 200 m

Figure 65. Distribution of spotted wolfish in the offshore of Nova Scotia from the DFO summer Research Vessel Survey.

The Atlantic wolffish, *Anarhichas lupus*, in the western Atlantic, occur from west Greenland south off the coasts of Newfoundland and Nova Scotia and occasionally stray as far south as New Jersey (Scott and Scott, 1988). The DFO groundfish surveys conducted since 1970 have encountered Atlantic wolffish over most of the Scotian Shelf with areas of higher abundance along the edge of the Laurentian Channel, around Brown's Bank, and in the Gulf of Maine (Figure 66). The DFO Georges Bank groundfish survey conducted since 1986 has found Atlantic wolffish concentrated along the northern edge of Georges Bank and along the Great South Channel (Figure 67).

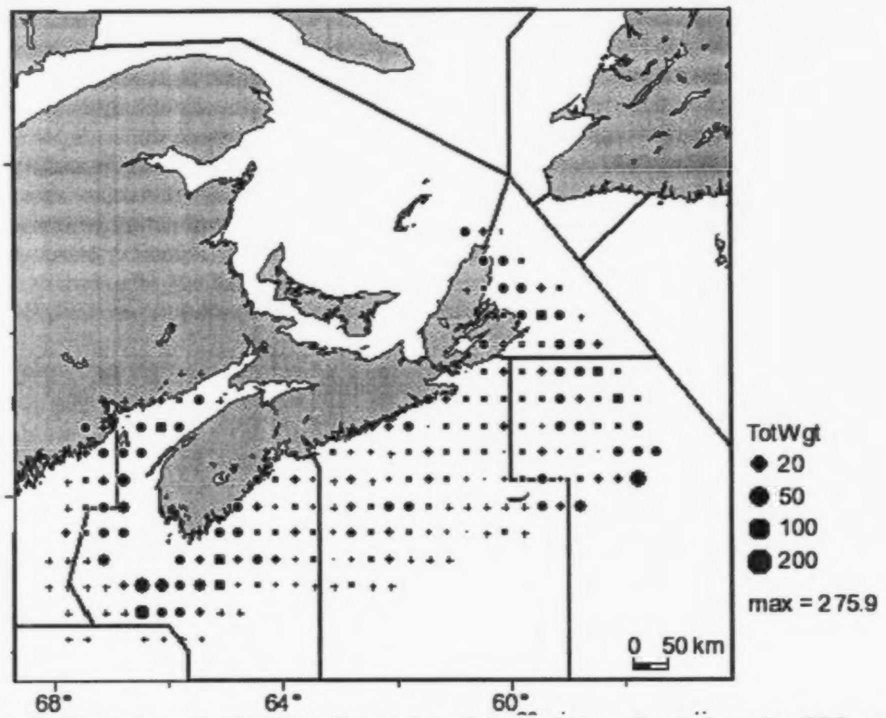

48°
44°
68°
64°
60°
TotWgt
● 20
● 50
● 100
● 200
max = 275.9
0 50 km

Figure 66. Distribution of Atlantic wolfish in the offshore of Nova Scotia from the DFO summer research vessel survey.

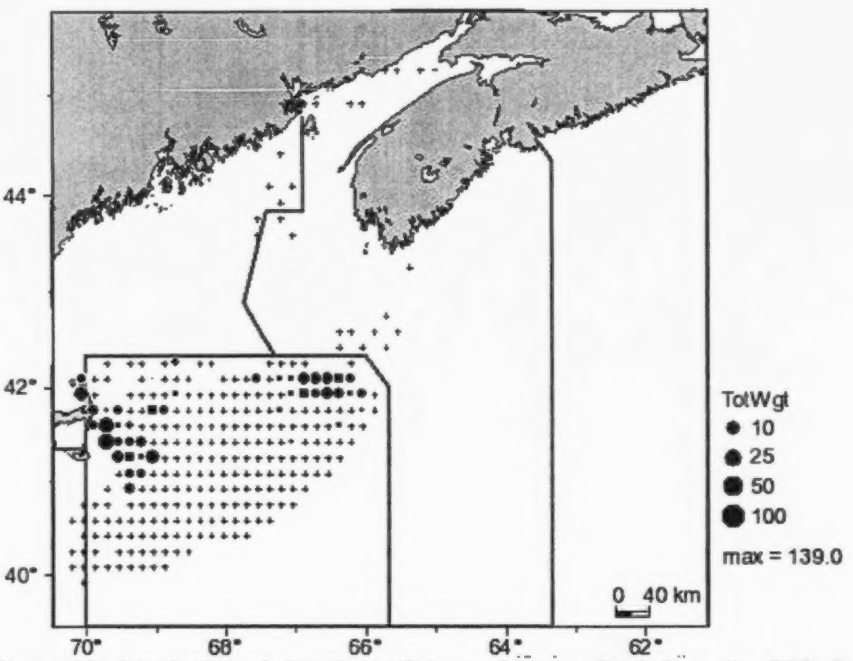

44°
42°
40°
70°
68°
66°
64°
62°
TotWgt
● 10
● 25
● 50
● 100
max = 139.0
0 40 km

Figure 67. Distribution of Atlantic wolfish on Georges Bank from the DFO Georges Bank research vessel survey.

9.10.1 Atlantic Wolffish

Distribution, Habitat, Abundance, and Predator and Prey

The Atlantic wolffish, *Anarhichas lupus*, is widely distributed on both sides of the North Atlantic. In the western Atlantic it is distributed from the Davis Strait in the north to the Nantucket Shoals in the south (Nelson and Ross, 1992). In Canadian waters, the greatest abundance occurs off the coast of Newfoundland. Wolffish are widely distributed over the entire Scotian Shelf and in the Bay of Fundy. Higher abundances occur in NAFO Division 4V along the Laurentian Channel and in 4X around Browns Bank and the Gulf of Maine (McRuer et al., 2000). Wolffish are distributed throughout the southern Gulf of Maine and Georges Bank area, however, concentrations can be found along the 100 m contour from the Northeast Peak to Jeffery's Ledge and along the Great South Channel (Nelson and Ross, 1992).

The Atlantic wolffish is solitary and sedentary and is found at depths up to 350 m (Albikovskaya, 1982). On the Scotian Shelf their preferred depth range is 75-130 m, with a preferred temperature range of 3-6 °C (Scott and Scott, 1988). In the southern Gulf of Maine and Georges Bank area their preferred depth range is 22-275 m (Nelson and Ross, 1992). They are found predominantly on rocky and hard clay bottoms (Nelson and Ross, 1992), however, they have been found in holes under large boulders when in shallow waters (Scott and Scott, 1988). The diet of Atlantic wolffish is composed primarily of benthic invertebrates (Scott and Scott, 1988). The diet in the Scotian Shelf to Labrador region consisted mainly of whelks, brittle stars, sea urchins, sand dollars, hermit crabs, and bivalves in decreasing order of importance (Templeman, 1985). In the Gulf of Maine and Georges Bank area, it was found that bivalves were the most important prey item, followed by echinoderms, gastropods, and decapods (Nelson and Ross, 1992).

Surveys from most parts of the western Atlantic indicate declines in abundance of Atlantic wolffish over the past 20 years. Since 1978, catch rates in Newfoundland have been down by 91% over two generations. Mean size has also declined and is now smaller than the size of maturity off Newfoundland. The stock is considered overexploited and depleted (COSEWIC, 2000). Surveys on the Scotian Shelf have also shown a decline through the 1980s, which has continued through to 2009 (Figure 68). Scotian Shelf surveys have also shown a decline in mean length and mean weight from a high in 1984 (mean length 55.4 cm and mean weight 2.5 kg) to a low in 2000 (mean length 37.9 cm and mean weight 1.4 kg). The DFO surveys on Georges Bank began in 1986 and show a steady decline over the time series (Figure 69).

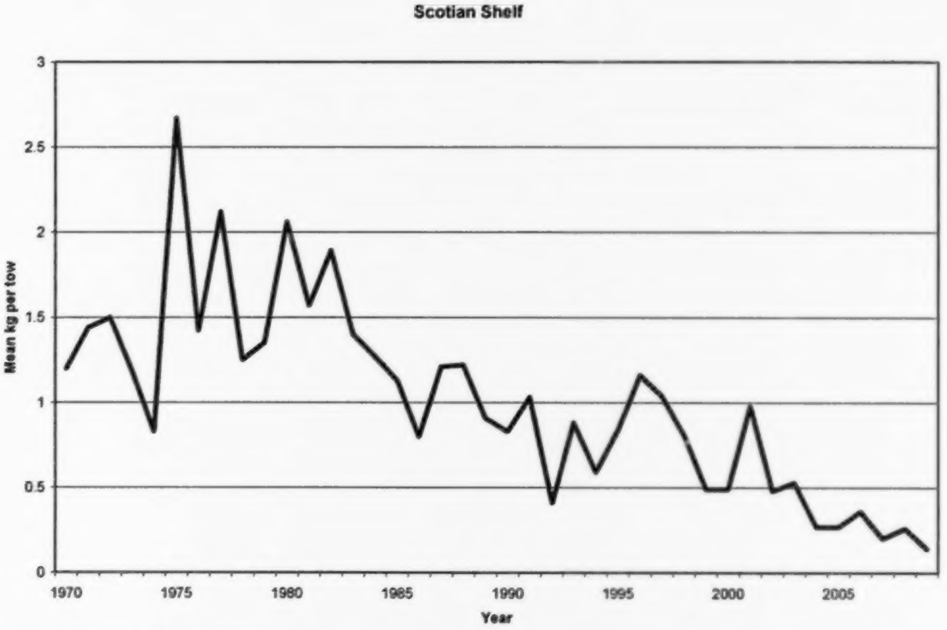


Figure 68. *Biomass of Scotian Shelf Atlantic wolffish from the DFO summer research vessel survey.*

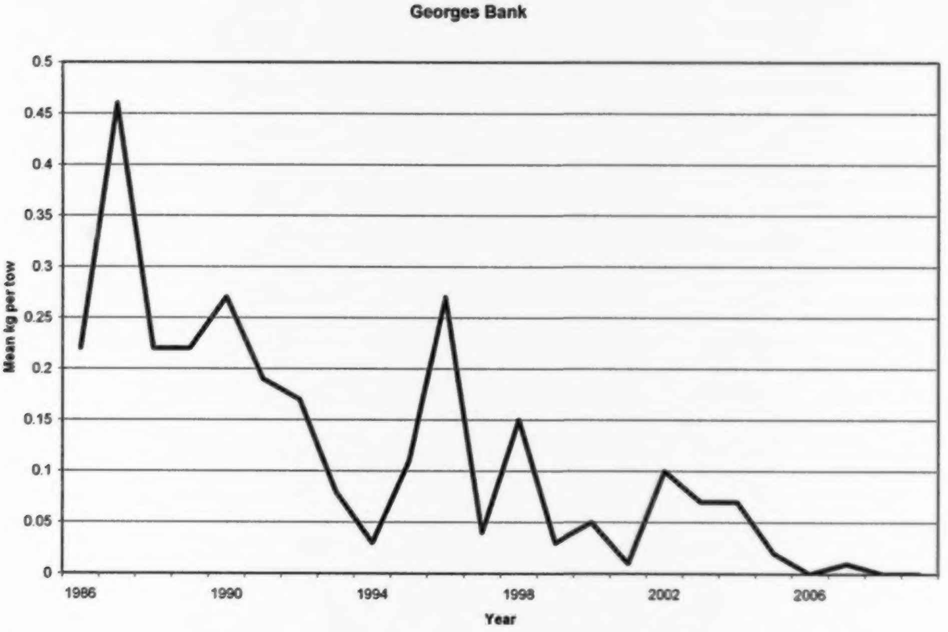


Figure 69. *Biomass of Georges Bank Atlantic wolffish from the DFO research vessel survey.*

Population Structure Relative to Moratorium Area

The population structure of Atlantic wolffish in the Gulf of Maine and Georges Bank area is unknown (DFO, 2002c). The species has a sedentary nature and movements seem to be limited to small scale spring spawning migrations to shallower waters (Nelson and Ross, 1992). It is possible that there may be small sub-populations of Atlantic wolffish in the area.

Life History, Timing, and Locations

The Atlantic wolffish spawning times vary greatly across its range. Off the east coast of Newfoundland, some Atlantic wolffish migrate to shallow waters in late spring with spawning taking place in mid-September (Scott and Scott, 1988). On the Scotian Shelf, egg masses have been found as early as February (McRuer et al., 2000). The fecundity of Atlantic wolffish is considered to be low, however, survival is considered to be relatively high (Scott and Scott, 1988). Atlantic wolffish deposit their eggs in a cohesive mass that is guarded by the male (Scott and Scott, 1988). On hatching, the larvae are pelagic and around 17 mm in length. The larvae remain close to the bottom and the entire larval stage is spent close to the spawning site (Collette and Klien-MacPhee, 2002). It is estimated that Atlantic wolffish reach sexual maturity between 8-10 years of age (Scott and Scott, 1988).

Known Vulnerabilities

Atlantic wolffish are characterized by low fecundity, relatively late age at maturation, sedentary lifestyle, benthic cohesive egg masses, and larval site fidelity. Given these factors and the poor understanding of the population structure of Atlantic wolffish, it is possible that a relatively localized mortality or reproductive disturbance could put a sub-population at risk.

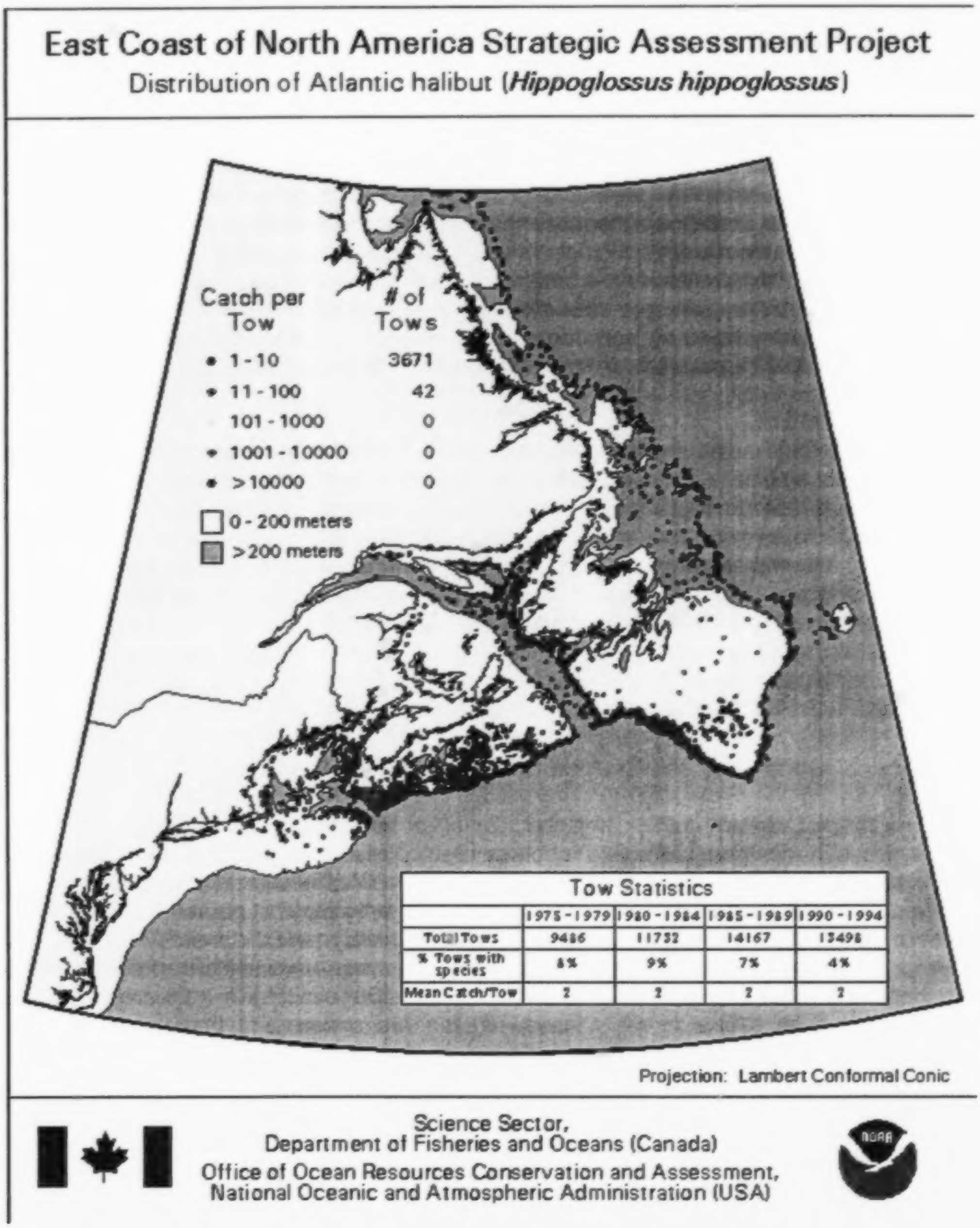
Status Designation

The Atlantic wolfish is listed as 'special concern' pursuant to SARA. It was designated as 'special concern' by COSEWIC in November 2000.

9.11 ATLANTIC HALIBUT

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic halibut, *Hippoglossus hippoglossus*, in the northwest Atlantic are distributed from north of Labrador south to Virginia and also occur off Western Greenland. They are considered a single population throughout their range (Scott and Scott, 1998). In Canadian waters, halibut range from the coast of Labrador, the Gulf of St. Lawrence, the eastern shores of Nova Scotia and Bay of Fundy (Figure 70), and are most abundant along the southern edge of the Grand Banks and on the Scotia Shelf from Browns to Banquereau Bank (Cargnelli et al., 1999). Juvenile halibut are quite localized, being found in nursery grounds and on coastal areas 20-60 m deep with sandy bottoms. Adults are found over sand, gravel, or clay substrates and prefer temperatures greater than 4°C (Cargnelli et al., 1999). On the Scotian Shelf, halibut are most abundant between 200-500 m water depth and can be found in deep channels between banks and at the edge of the continental shelf over sand, gravel, or clay substrates. Halibut move from shallower into deeper water in the winter, returning to shallow waters in summer (Scott and Scott, 1998; DFO, 2009d).



East Coast of North America Strategic Assessment Project

Distribution of Atlantic halibut (*Hippoglossus hippoglossus*)

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	8%	9%	7%	4%
Mean Catch/Tow	2	2	2	2

Projection: Lambert Conformal Conic

Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

***Figure 70.** Distribution of Atlantic halibut in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

As halibut increase in size, prey selection shifts from invertebrates to fish. Small halibut feed on cephalopods, large crustaceans, and benthic invertebrates including shortfin squid, hermit and small crabs, prawns, and mysids, while larger halibut consume cod, haddock, sand lance, redfish, pollock, wolffish, herring, and capelin (Cargnelli et al., 1999). Since the early 1990s, there appears to have been a significant reduction in the numbers of halibut in the northern and southern extent of its range, in U.S. waters (Kanwit, 2007), and along the Labrador Shelf.

The biomass of Atlantic halibut on the Scotian Shelf and Southern Grand Banks (3NOPs4VWX5Zc) has increased since 2003. The biomass estimate varies from 6498-8333 t, with an annual increase of 252 t per year over the entire stock unit and 315 t per year in 4VWX (DFO, 2009d). The DFO RV and halibut surveys indicate that the number of pre-recruits (fish greater than 81 cm in length) is above the long-term average (0.192 halibut per standard tow) and has been increasing since 2004. Surveys completed by the Northeast Fishery Science Center indicate that biomass in the Gulf of Maine and Georges Bank remains very low. Population size indices have fluctuated considerably since the 1960s and have declined overall. The survey indices for 2002-2005 ranged from a high of 554 t in 2004 to a low of 83 t in 2005 (Mayo and Terceiro, 2005).

Population Structure Relative to Moratorium Area

The stock structure of Atlantic halibut is not well defined. The majority of fish do not move between NAFO divisions, however, individuals may roam extensively within their range (Scott and Scott, 1998) and are considered a transboundary stock. Tagging studies have documented long distance migrations from Labrador to Greenland, the Gulf of St. Lawrence to Iceland, and the Scotian Shelf to the Grand Banks. Migrations of larger fish to deeper water in autumn are thought to be related to spawning. Studies have shown that the Browns Bank area may be an important rearing area for juvenile halibut populating the Scotian Shelf and southern Grand Banks. Juveniles emigrate from nursery areas at 3-4 years and undergo north-eastward movement as they grow (Cargnelli et al., 1999).

Life History, Location, and Timing

Halibut are sexually dimorphic, with females being substantially larger than males. Halibut live up to 50 years and reach sexual maturity at 5 and 9, respectively, for males and females (Trzcinski et al., 2009). The median age in the Gulf of Maine and Georges Bank region is approximately 7 years (Sigourney et al., 2006). Females are batch spawners, producing several batches of eggs each year. Spawning is thought to occur in waters along the slope of banks and the continental slope at depths of 200 m or greater during late fall, winter and early spring, peaking from November to December. Eggs are suspended in the water column from 54-200 m below the surface and are thought to develop near the seabed. Settlement is thought to occur at 34-40 mm in length (Cargnelli et al., 1999).

Known Vulnerabilities

The vulnerabilities of Atlantic halibut are not known.

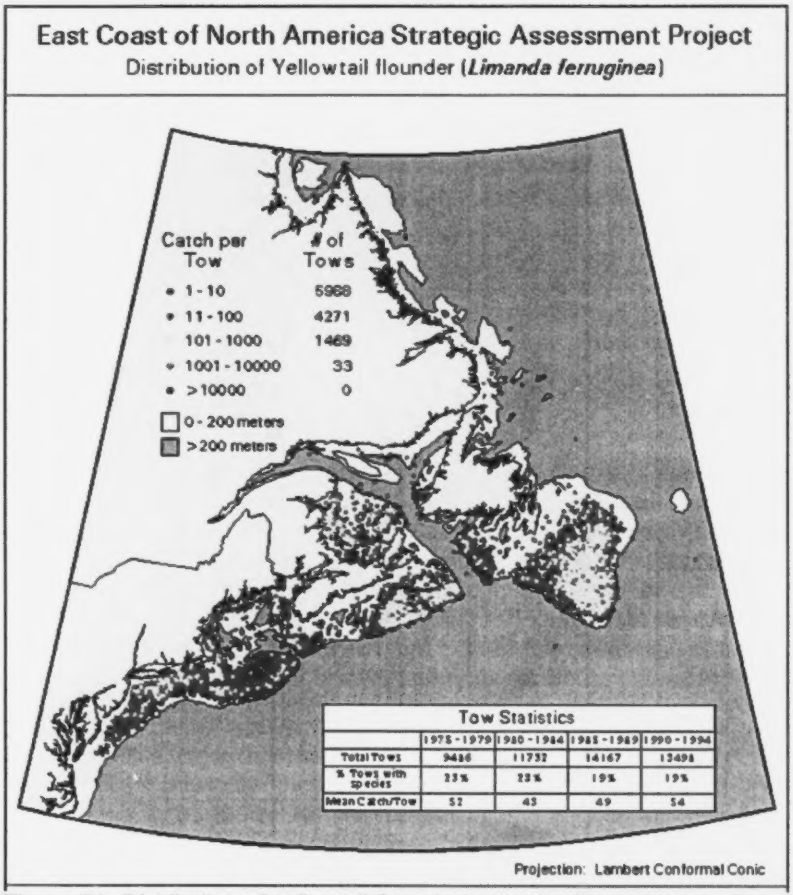
Status Designation

Atlantic halibut is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.12 YELLOWTAIL FLOUNDER

Distribution, Habitat, Abundance, and Predator and Prey

Yellowtail flounder, *Limanda ferruginea*, is a small-mouthed Atlantic flatfish species that inhabits sandy substrates in relatively shallow waters of the continental shelf of the western north Atlantic from southern Labrador to Chesapeake Bay (Figure 71) (Bigelow and Schroeder, 1953, TRAC, 2009d). A major concentration of yellowtail flounder occurs on Georges Bank from the Northeast Peak to the Great South Channel (Legault et al., 2009). On Georges Bank, adult yellowtail flounder are found primarily at depths between 37-73 m, where they show a preference for sand or sand-mud sediments (Scott and Scott, 1988; Johnson et al., 1999).



East Coast of North America Strategic Assessment Project

Distribution of Yellowtail flounder (***Limanda ferruginea***)

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	23%	23%	19%	19%
Mean Catch/Tow	52	43	49	54

Projection: Lambert Conformal Conic

Figure 71. *Distribution of yellowtail flounder in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Yellowtail flounder have a small mouth that restricts their choice of food. They feed primarily on benthic macrofauna, with prey consisting of amphipods, polychaete worms, mysids, and sand dollars, as well as small quantities of other invertebrates and small fishes (Langton, 1983; Hahm and Langton, 1984; Collie, 1987; Johnson et al., 1999;

Bruno et al., 2000). Arthropods and annelids dominated the yellowtail flounder stomach contents collected during the NEFSC spring survey of Georges Bank between 1973-1990 (Johnson et al., 1999). Yellowtail flounder feed primarily during daylight hours. Studies from NAFO Divisions 3NO demonstrated that stomachs contained the least amount of food at dawn and the most at dusk, indicating that feeding began near sunrise and ended near sunset (Bruno et al., 2000). Similarly, the highest stomach content weights occurred in the afternoon to early evening in samples collected from southern New England and Georges Bank (Langton, 1983).

The Georges Bank yellowtail flounder stock is jointly managed by the Canada and the U.S. through the Transboundary Management Guidance Committee (TMGC). Stock assessments are conducted annually by the Transboundary Resources Assessment Committee (TRAC). Estimates of abundance are based on bottom trawl survey observations and the range of results from plausible age structured analytical assessments (i.e Virtual Population Analysis, or VPA) that use fishery catch statistics and sampling for size and age composition of the catch. The VPAs were calibrated to trends in abundance from three bottom trawl survey series (U.S. NMFS spring, NMFS fall, and DFO Georges Bank spring) and a recruitment index from the NMFS summer sea scallop survey. In 2008 and 2009, the DFO surveys recorded individual tows that were much larger than any seen previously in the time series. These individual tows had a strong influence on the estimates for those years, so two VPAs were run, one with and one without the 2008 and 2009 DFO survey data (Legault et al., 2009) (Figure 72).

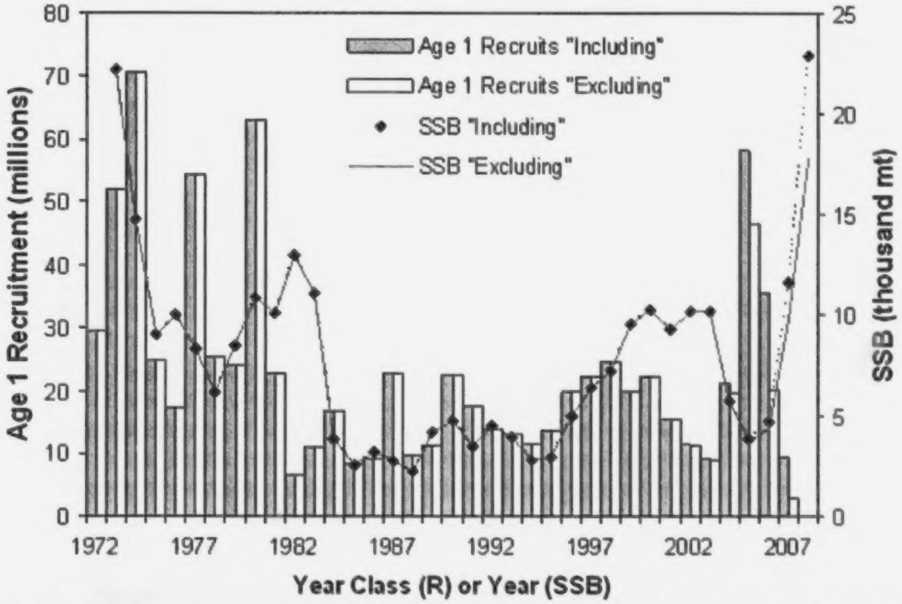


Figure 72. *Spawning Stock Biomass, or SSB (lines), and Age 1 recruitment (bars) of yellowtail flounder. 'Including' refers to the VPA run that included the DFO 2008 and 2009 survey information and 'Excluding' refers to the VPA run that excluded it (TRAC, 2009d).*

Yellowtail flounder adult biomass (age 3+) increased from a low of 2100 t in 1995 to 11,000 t in 2003, declined to 3300 t in 2006, and increased to 20,600 t (excluding the 2008/2009 DFO surveys in the VPA) or 28,000 t (including the 2008/2009 DFO surveys in the VPA) at the beginning of 2009. This was the highest adult biomass observed since

1973. Spawning stock biomass in 2008 was estimated to be 17,800 t (excluding the 2008/2009 DFO surveys) or 22,900 t (including the 2008/2009 DFO surveys). From 1998 to 2001, recruitment averaged 22.3 million fish at age 1, but has been below 20 million fish since then. The exception has been the above average 2005 year-class estimated at 46.6 million fish, which is the strongest year-class since the 1980 cohort (TRAC, 2009d).

Population Structure Relative to Moratorium Area

The management unit currently recognized by Canada and the U.S. for the transboundary Georges Bank yellowtail flounder stock includes the entire Bank east of the Great South Channel to the Northeast Peak (Gavaris et al., 2005). Tagging observations, larval distribution, life history traits, geographic patterns of landings, and survey data indicate Georges Bank yellowtail flounder from this management unit comprise a relatively discrete stock, separate from those on the western Scotian Shelf, off Cape Cod and southern New England (Royce et al., 1959; Lux, 1963; Neilson et al., 1986; Begg et al., 1999; Cadrin, 2003; Stone and Nelson 2003; Stone et al., 2004), with little movement into the adjacent stock areas (Cadrin, 2006). Tagging on the U.S. side of Georges Bank has demonstrated frequent movements in the stock area, where fish moved an average of 42 km between their release and recapture sites, with differences in distance traveled based on fish gender and season of recapture (Cadrin et al., 2004; Zeiber, 2008). Vertical off-bottom migration during the evening hours has also been demonstrated using archival tags (Cadrin and Moser, 2006).

Life History, Location, and Timing

Yellowtail spawning occurs on Georges Bank from late-March until early-August, peaking in May. From the distribution of both ichthyoplankton and mature adults, it appears that spawning occurs on both sides of the Canada and U.S. boundary line. Yellowtail flounder mature earlier than most flatfish, with approximately half of the age 2 females being mature and nearly all of the age 3 females being mature (Legault et al., 2009). Yellowtail flounder are batch spawners (Murua and Saborido-Rey, 2003), depositing their eggs on or near the bottom. After fertilization, the buoyant eggs float to the surface where they drift during development (Legault et al., 2009).

The eggs hatch after approximately 1-3 weeks depending on the water temperature, with the most dense egg concentrations occurring on the northeast and southwest part of Georges Bank (Johnson et al., 1999). Larvae are pelagic for a month or more and then they become demersal and settle to benthic habitats (Legault et al., 2009). The larvae are found on Georges Bank from April to August, with the highest concentrations occurring in June (Johnson et al., 1999). In the spring, juvenile and adult yellowtail flounder are concentrated on the southern edge and northeast peak of Georges Bank, but they are more widely distributed across the Bank at other times of year.

Known Vulnerabilities

Georges Bank yellowtail flounder is a bottom dwelling fish that does not migrate off the Bank. It depends on sand and sand/mud substrate on the Bank, lays its eggs on or near the bottom, and feeds on benthic macrofauna. As a result, it may be vulnerable to any disturbance of the bottom.

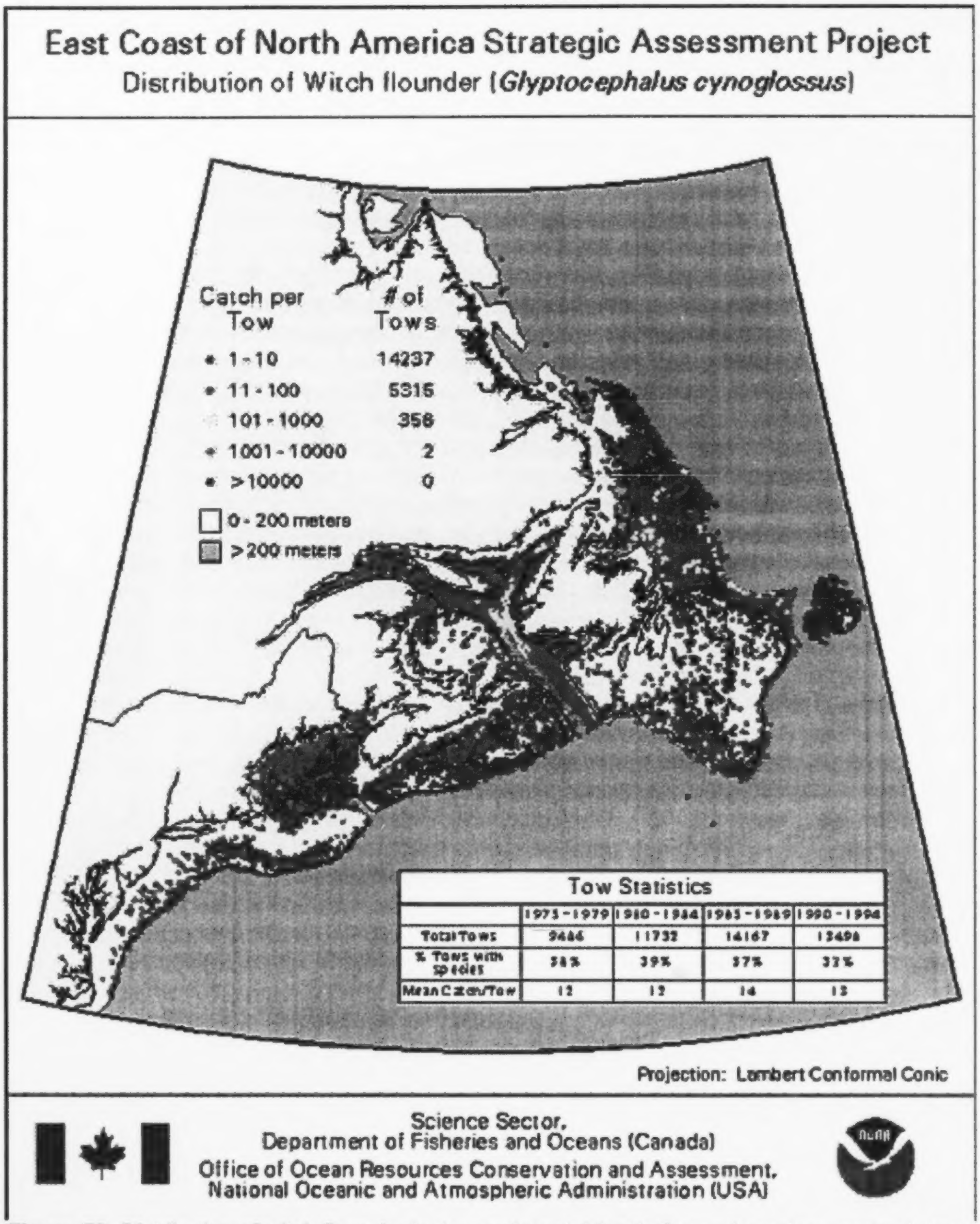
Status Designation

Yellowtail flounder is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.13 WITCH FLOUNDER

Distribution, Habitat, Abundance, and Predator and Prey

Witch flounder, *Glyptocephalus cynoglossus*, is a deep water boreal flatfish occurring on both sides of the North Atlantic. In the northwest Atlantic, witch flounder are distributed from Labrador to Georges Bank and in the continental slope waters southward to Cape Hatteras, North Carolina, usually at 50-300 m in water of 2-6 °C (Figure 73). They occur most commonly in deep holes and channels and along the shelf slope on muddy bottoms. There is no evidence of extensive migrations, but there are seasonal changes in concentration associated with spawning (McRuer et al., 1997; Scott and Scott, 1988).


East Coast of North America Strategic Assessment Project
Distribution of Witch flounder (*Glyptocephalus cynoglossus*)
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Catch per Tow	# of Tows
● 1 - 10	14237
● 11 - 100	5315
● 101 - 1000	358
● 1001 - 10000	2
● >10000	0
☐ 0 - 200 meters	
▨ >200 meters	

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9446	11732	14167	13496
% Tows with species	38%	39%	37%	33%
Mean Catch/Tow	12	12	14	13

Figure 73. *Distribution of witch flounder in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Witch flounder diet consists of polychaete worms, benthic invertebrates such as small crustaceans, bivalve molluscs and echinoderms and rarely small fish. There is a distinct shift in diet with polychaetes increasing in importance with age. By sexual maturity, polychaetes dominate the diet (Wigley et al., 2003). The 1997 stock status report for witch flounder on the Scotian Shelf reported that populations declined substantially in abundance between the mid-1980s and the mid-1990s and the harvest portion of the population was at the lowest level observed at that time. A 2003 assessment of the Gulf of Maine and Georges Bank population in U.S. waters indicated that abundance sharply increased in 1993 and had continued to increase to near record levels in 2002, however, the age composition still remains truncated with a striking decline in the number of older fish (Wigley et al., 2003).

Population Structure Relative to Moratorium Area

The stock structure of witch flounder is not known. Witch flounder are a rather sedentary species that do not undertake long-distance migration, with concentrations of witch flounder in the western 4X continuous with those in the rest of the Gulf of Maine. (DFO, 2002b; Wigley et al., 2003).

Life History, Location, and Timing

Female witch flounder live longer and grow larger than males (Scott and Scott, 1988). Median age at sexual maturity for male witch flounder is 4 years and 6.5 years for females. Witch flounder spawn from March to November, with peak spawning occurring in summer. The general trend is for spawning to occur progressively later from south to north. In the Gulf of Maine-Georges Bank region, spawning occurs in dense aggregations associated with areas of cold water from April to November and peaks from May to August. The western and northern areas of the Gulf of Maine tend to be the most active spawning sites. Spawning occurs at or near the bottom, although the buoyant eggs rise into the water column where subsequent egg and larvae development occurs. Hatching occurs 7-8 days after spawning. The post-larval pelagic phase is usually long, lasting up to one year, and it is thought that the first few years of demersal life are spent in much deeper water than the adults (DFO, 2002b; Wigley et al., 2003).

Known Vulnerabilities

Witch flounder is a bottom dwelling species. Given the benthic nature of the species it is possible that witch flounder may be vulnerable to bottom activites causing disturbances or contamination.

Status Designation

Witch flounder is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.14 SKATES

Scotia Fundy and U.S. RV survey data was examined to determine the distribution and relative abundance of the most common skate species found to occur on the Northeast Peak of Georges Bank. Skate species caught in order of abundance during the Canadian RV survey are: winter skate (*Leucoraja ocellatta*); little skate (*Leucoraja erinacea*); thorny skate (*Amblyraja radiate*); and barndoor skate (*Dipturus laevis)*, and smooth skate (*Malacoraja senta*).Two other species, the rosette skate (*Leucoraja garmani*) and the clearnose skate *(Raja eglanteria)* have been reported from U.S. waters but are uncommon on Georges Bank.

Winter skate and little skate are the most abundant skate species on the Northeast Peak and are widely distributed across the entire bank. Since 1987, no trend in abundance is evident in either species. Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature. Thorny skate are the third most common skate species caught during the Canadian RV survey and are found on the edges of the Northeast Peak and north of the Great South Channel in the Gulf of Maine. Thorny skate abundance has declined on the Northeast Peak since the early 1990s to very low levels. Barndoor skate are caught primarily on the southern flank of Georges Bank, with no separation in the distribution between the Canadian and U.S. zones. Smooth skate are not commonly caught during the Canadian RV survey given the depth distribution of the survey sets. They are found on the edges of the Bank in the Canadian zone and in the Gulf of Maine in the same area as thorny skate. Smooth skate and barndoor skate abundance has remained low without any obvious trend since the beginning of the time series.

9.14.1 Winter Skate

Distribution, Habitat, Abundance, and Predator and Prey

Winter skate, *Leucoraja ocellata,* are found from Cape Hatteras to the Gulf of St. Lawrence/southern coast of Newfoundland, based on Canadian and U.S. RV survey data (Simon et.al. 2003; COSEWIC 2005a; NEFSC, 2007). The highest concentrations have been found on Georges Bank and the offshore banks of the Scotian Shelf. In this broad geographic range, winter skate have been reported from less than 1m in depth to 371 m depth (McEachern, 2002; Scott and Scott, 1988). The Canadian RV winter survey of Georges Bank indicated that winter skate is abundant throughout Georges Bank, with the highest concentrations residing on the U.S. side of the Bank (Figure 74). Approximatley 70% of the sets in this survey contained winter skate. The area of occupancy of this species has been stable. Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature.

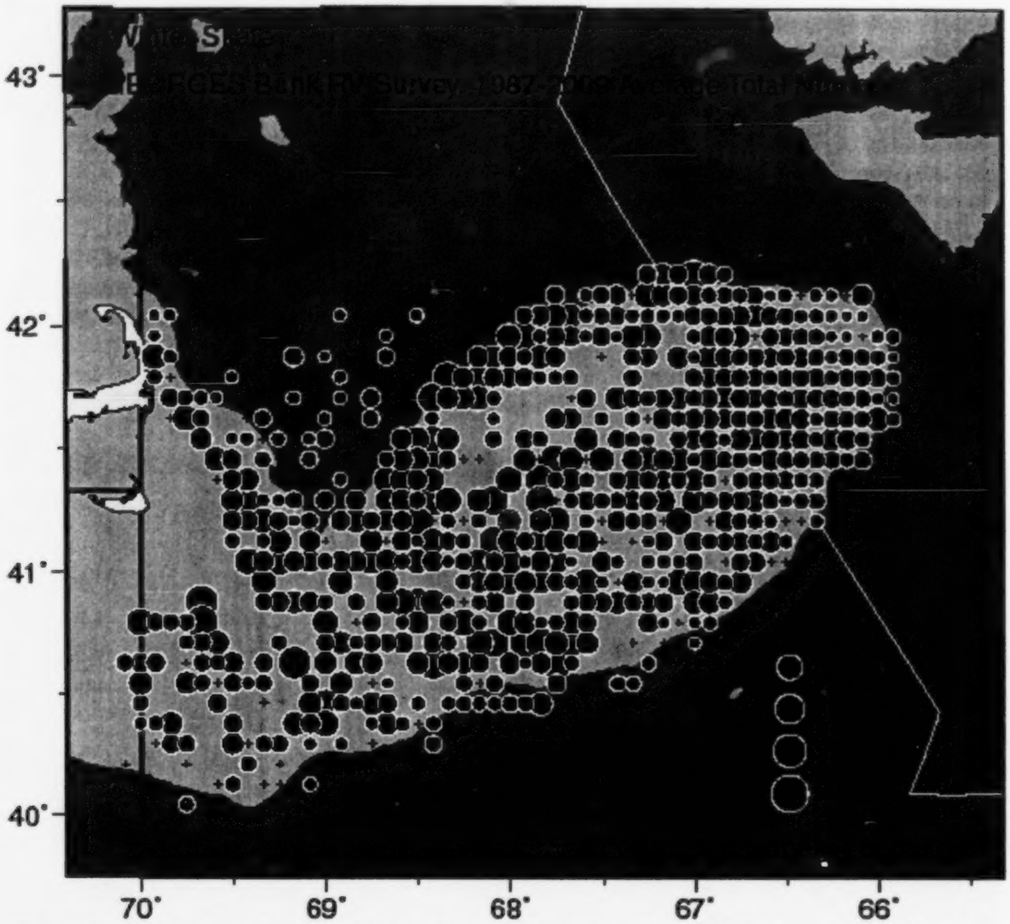


Figure 74. *Distribution of winter skate on Georges Bank from the DFO Georges Bank RV survey.*

Crustaceans make up more than 50% of the diet of Georges Bank winter skate greater than 61 cm in length, while fish dominate the diet of skate greater than 91 cm in length. Among the most common prey items for all sizes of skate are sand shrimps, Jonah crab, rock crab, hermit crab, isopods, and sand lance. Other fish prey includes silver hake, herring, longhorn sculpins, and other skates (McEachern et al., 1976; Packer et al., 2003a).

The population biomass of Eastern Georges Bank winter skate, as calculated from the Canadian RV survey, has fluctuated between 800-5900 t from 1987-2009 without trend, although the 2009 estimate is the highest in the series (Figure 75). Abundance (number per tow) was generally higher in the beginning of the series, declined to a low in 1997, and has since recovered to near average values. The larger scale spring and fall U.S. RV surveys were examined from 1967-2006, in order to put the results of the Canadian RV data into a broader context. In general, abundance was low in both surveys until 1980, increased rapidly to a peak in the mid 1980s, and subsequently fell to estimates seen in the beginning of the two surveys (NEFSC, 2007).

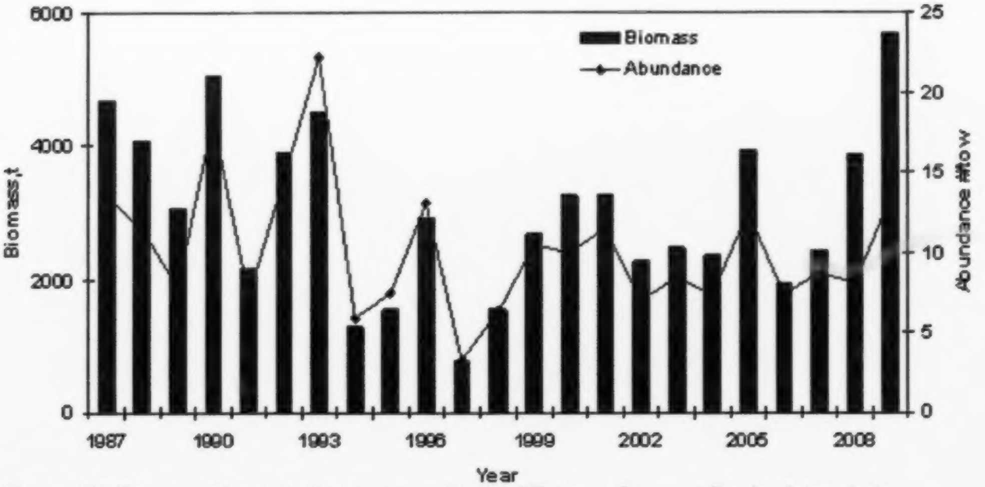


Figure 75. *Biomass (bars) and abundance (line) of Eastern Georges Bank winter skate.*

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate that winter skate are widely distributed in the spring over the Georges Bank region south to Cape Hatteras, while in the fall adults are more concentrated on the Bank (NEFSC, 2007). The U.S. nearshore RV surveys also suggest that juveniles exhibit an onshore-offshore seasonal migration (NEFSC, 2007). Given the continuous distribution of winter skate, as demonstrated in Figure 74, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between winter skate on Georges Bank and Brown's Bank is unknown although, given the depth preferences of the species and the depth of the Fundian Channel, it is unlikely that there is wide scale movement between these two locations.

Life History, Location, and Timing

Skate are oviparous, depositing a single egg in a leathery capsule (purse), which is extruded. The purse has adhesive mucus that attaches to substrate materials and helps it to maintain contact with the bottom. Observations suggest that it may take as long as 22 months for the purse to hatch on the Scotian Shelf, but no such observations exist for Georges Bank (Simon and Frank, 1998). It is likely that less than 100 purses per female are produced per anum. In the western Gulf of Maine, a peak in purse production was observed from September to November, although winter skate have also been observed with purses throughout the year (Packer et al., 2003a). On the Scotian Shelf, deposition of egg-cases has been observed in the fall (Simon and Frank, 1998). This suggests that winter skate 'spawn' in the Georges Bank Moratorium Area in the fall, but spatial and temporal details are unknown. Upon hatching, the juveniles are approximately 12 cm in length (Sulikowski et al., 2003).

Known Vulnerabilities

Winter skate life history characteristics increase its vulnerability to exploitation, reduce its rate of recovery, and increase its risk of extinction (Swain et al., 2006). Such characteristics include: delayed age at maturity; long generation time; low fecundity; and slow population growth rate. Given the benthic nature of juveniles and adults, it is possible that winter skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

The Georges Bank-Western Scotian Shelf-Bay of Fundy population of winter skate is not listed pursuant to SARA, although it has been designated as 'special concern' by COSEWIC.

9.14.2 Little Skate

Distribution, Habitat, Abundance, and Predator and Prey

Little skate, *Leucoraja erinacea,* are found from Cape Hatteras to the Sable Island Bank on the Scotian Shelf, based on U.S. and Canadian RV survey data (NEFSC, 2007). They are most abundant on Georges Bank and in southern New England waters. The distribution pattern from the Canadian RV survey revealed that little skate are abundant throughout Georges Bank, with the highest concentrations on the U.S. side of the Bank (Figure 76). Approximately 60% of sets in the survey contain little skate, while the area of occupancy of this species has been stable. In this broad geographic range, little skate are most common at depths less than 111 m, but have been reported at depths down to 384 m (Scott and Scott, 1998; McEachern, 2002). Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature.

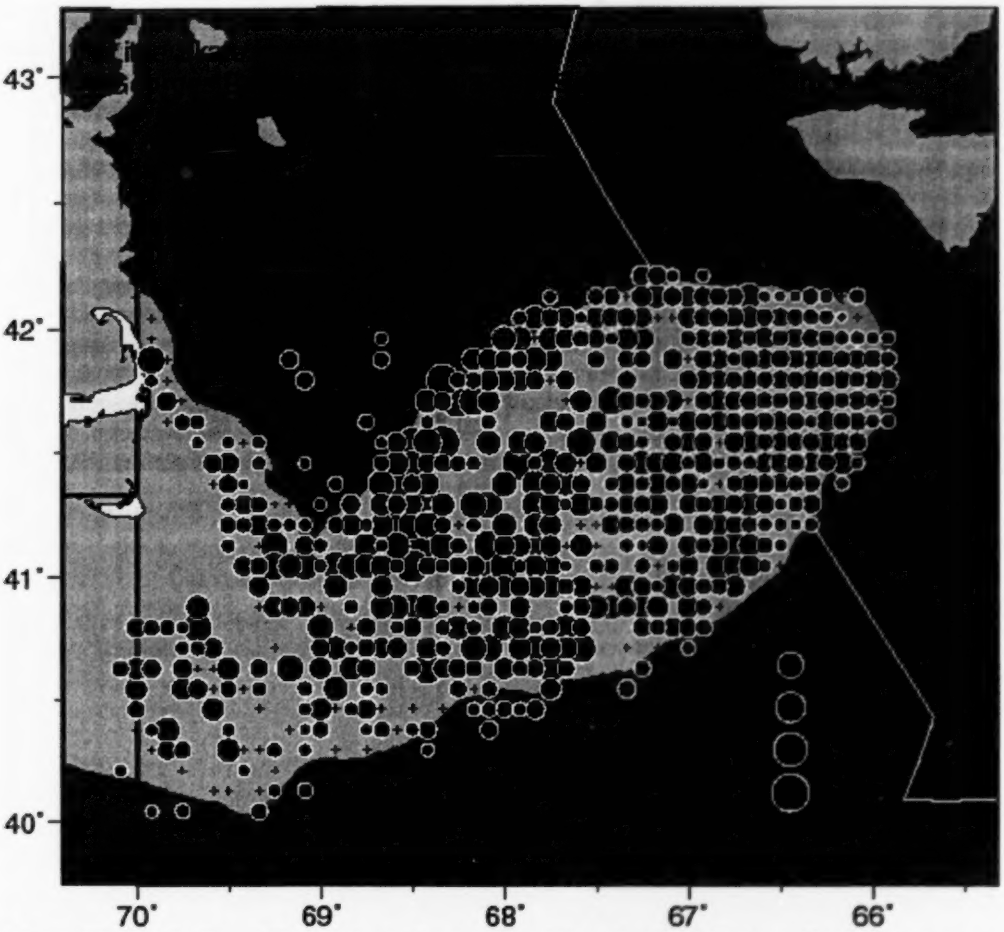


Figure 76. *Distribution of little skate on Georges Bank from the DFO Georges Bank RV survey.*

Invertebrates, such as decapod crustaceans and amphipods, followed by polychaetes, are the most important prey items of little skate. Isopods, bivalves, and fish are of minor importance. Fish that are eaten include sand lance, alewives, herring, cunners, and silver hake (Packer et al., 2003b). In general, little skate prey on infaunal species, while winter skate eat primarily epifaunal species.

The population biomass of Eastern Georges Bank little skate, as calculated from the Canadian RV survey, has fluctuated between 700-2300 t from 1987-2009, without trend (Figure 77). Abundance (number per tow) has also fluctuated without trend since the beginning of the series. The spring and fall U.S. RV surveys that survey from the Gulf of Maine to the Mid-Atlantic Bight were examined from 1975-2006 to put the DFO Georges Bank RV data into context. In general, abundance increased from the beginning of the spring survey to a peak in 2000. Abundance subsequently declined to near the average estimate. The fall survey estimates have increased slightly over the entire survey series (NEFSC, 2007).

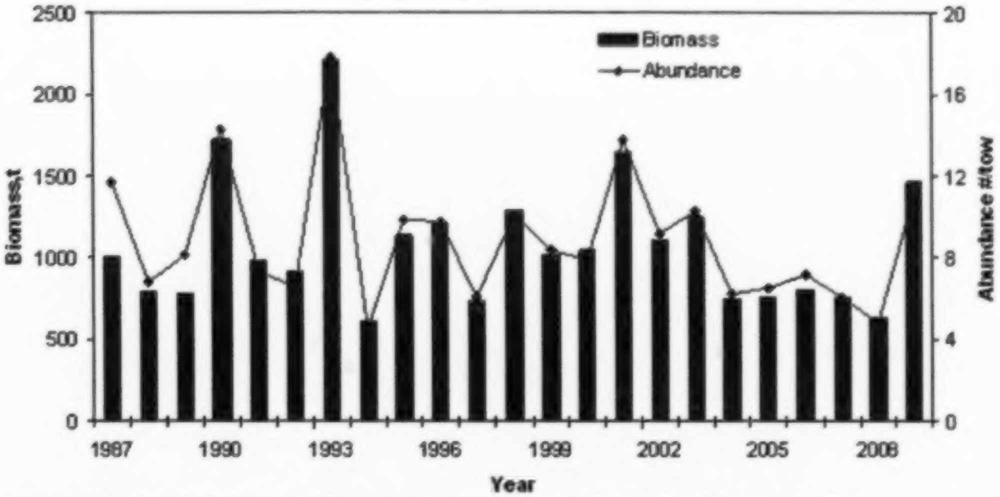


Figure 77. *Biomass (bars) and abundance (line) of eastern Georges Bank little skate.*

Population Structure Relative to Moratorium Area

The Canadian and U.S. RV seasonal surveys indicate that little skate are widespread and abundant over the Georges Bank moratorium area throughout the year (NEFSC, 2007). Given the continuous distribution of little skate, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between little skate on Georges Bank and Brown's Bank is unknown although, given the depth preferences of the species and the depth of the Fundian Channel, it is unlikely that there is wide scale movement between these two banks.

Life History, Location, and Timing

Skate are oviparous, depositing a single egg within a leathery capsule (purse), which is extruded. The purse has adhesive mucus that attaches to substrate materials and helps it to maintain contact with the bottom. Fully developed egg cases have been observed in U.S. waters throughout the year, with peaks in egg deposition in the fall and winter (Packer et al., 2003b). Annual production in females that have the two peaks is in the order of 30 per year. Preliminary data from the 2010 Canadian Georges Bank RV survey indicate that both winter and little skate purses have been observed on either side of the Canada/U.S. border. This suggests that little skate 'spawn' in the Georges Bank Moratorium Area, but spatial and temporal details are not complete at this time. Upon hatching, the juveniles are approximately 10 cm in length.

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that little skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Little skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.14.3 Thorny Skate

Distribution, Habitat, Abundance, and Predator and Prey

Thorny skate, *Amblyraja radiate*, are at the southern limit of their range on the Northeast Peak of Georges Bank and the Gulf of Maine, based on Canada and U.S. RV survey data (NEFSC, 2007). They are uncommon on the shallowest parts of the Bank (Figure 78). On the Northeast Peak they are primarily restricted to depths greater than 60 m. In this area, the area of occupancy has been declining since the beginning of the survey and they are now caught in approximately 10% of the survey sets.

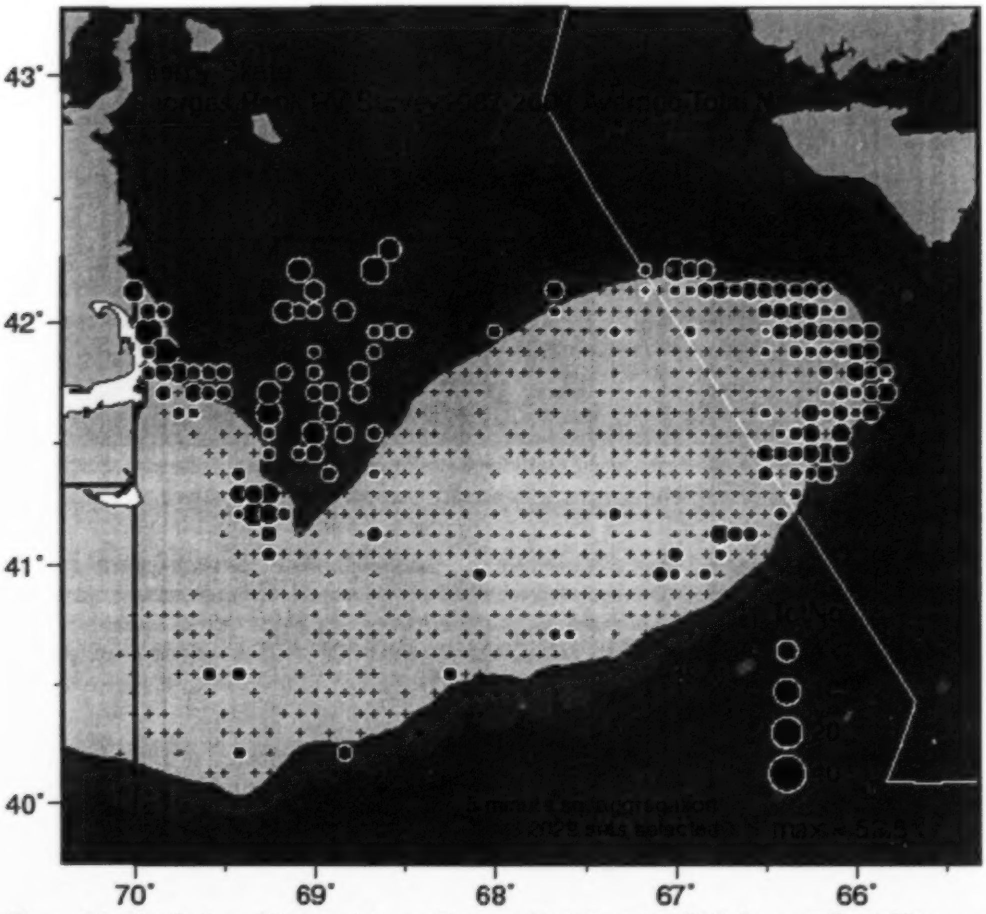


Figure 78. *Distribution of thorny skate on Georges Bank from the DFO Georges Bank RV survey.*

A wide variety of prey items have been reported to have been eaten by thorny skate. The percent composition of invertebrates such as decapod crustaceans, amphipods, and polychaetes varies with size of the predator, with fish being added as a prey item in the larger thorny skate. The fish most commonly reported as prey include sand lance, longhorn sculpins, and hagfish, although they are not a major component of the diet (Packer et al., 2003c).

The population biomass of Eastern Georges Bank thorny skate, as calculated from the DFO Georges Bank RV survey, has declined from approximately 300 t in the late 1980s to less than 100 t in recent years (Figure 79). The 2009 estimate is the lowest in the series. Abundance (number per tow) has also declined over the period of the survey. An examination of the spring and fall U.S. RV surveys from 1967-2006 indicates that this decline began in the early 1970s (NEFSC, 2007).

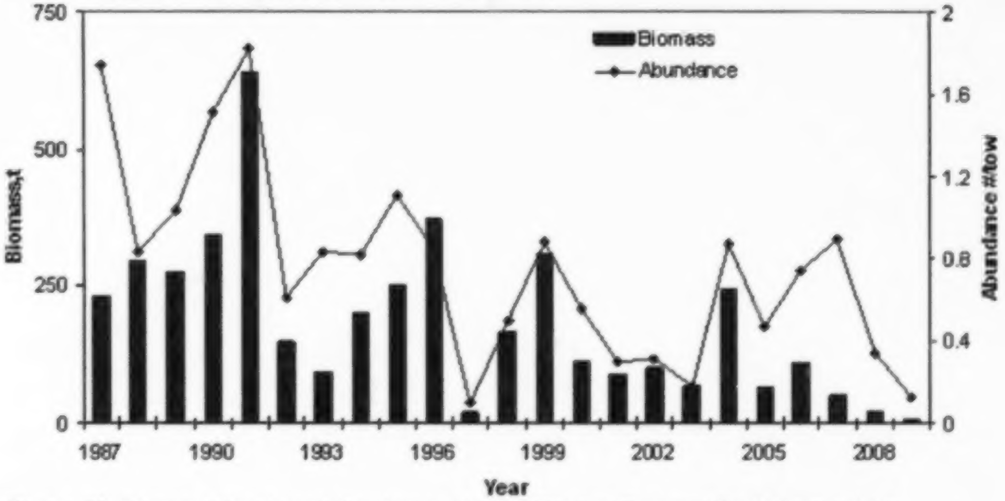


Figure 79. *Biomass (bars) and abundance (line) of Eastern Georges Bank thorny skate.*

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate that thorny skate are primarily caught in the Gulf of Maine, as well as in the same area of the Northeast Peak as found in the Canadian RV survey (NEFSC, 2007). Thorny skate of the Northeast Peak are likely associated with those found in the adjacent waters of the Gulf and the Fundian Channel, but there is no data to confirm this assumption.

Life History, Location, and Timing

Mature female thorny skate have been observed with partially developed egg capsules in April, June, July, and September in the Gulf of Maine, but no such observations have been reported for Georges Bank (Packer et al., 2003c).

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that thorny skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Thorny skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.14.4 Smooth Skate

Distribution, Habitat, Abundance, and Predator and Prey

The smooth skate, *Malacoraja senta*, is a boreal species that ranges from north of the Grand Banks to South Carolina (Scott and Scott, 1988; McEachern, 2002). Although the geographic centre of distribution is the Gulf of Maine, it is more common further north and is uncommon south of Georges Bank. They are primarily restricted to depths greater than 90 m and are, therefore, uncommon on Georges Bank. On the Northeast Peak, they are more abundant on the northern edge than elsewhere (Figure 80).

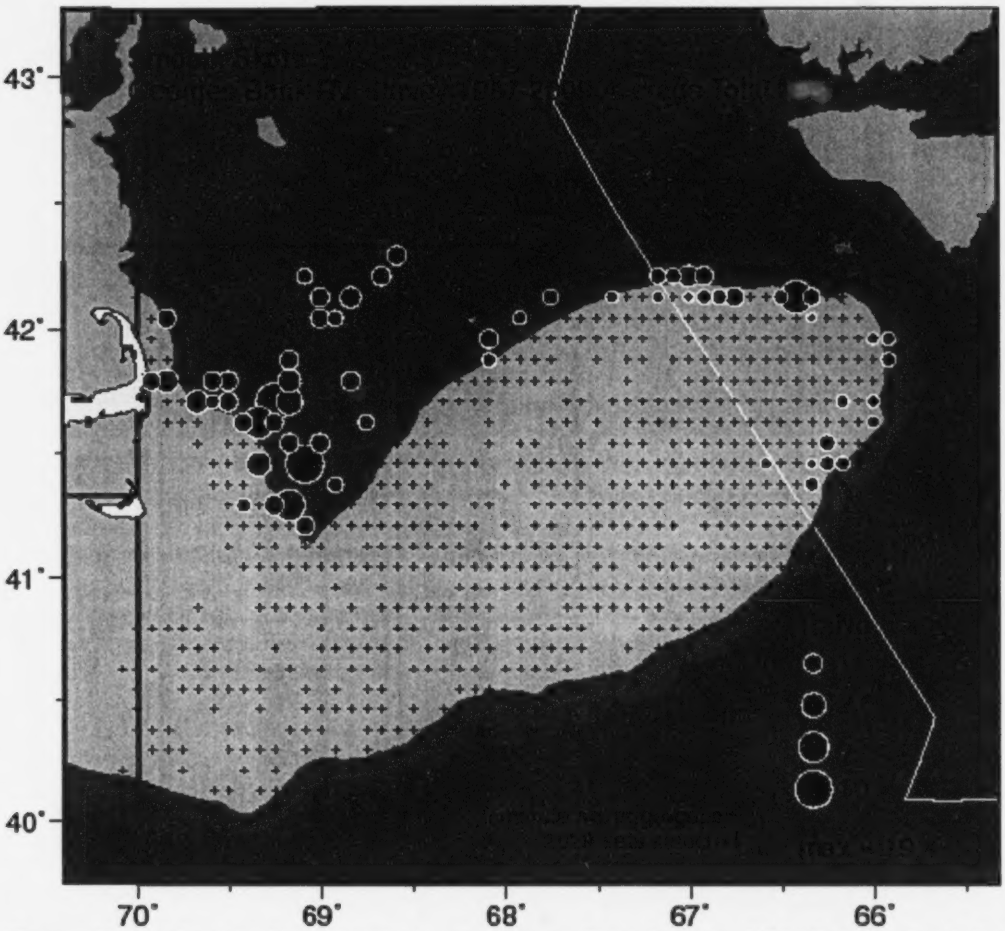


Figure 80. *Distribution of smooth skate on Georges Bank from the DFO Georges Bank RV survey.*

Smooth skate have a specialized diet that consists primarily of amphipods, euphasids, decapods, and mysids (Packer et al., 2003d). The population biomass and abundance (number per tow) of Eastern Georges Bank smooth skate, as calculated from the DFO Georges Bank RV survey, is very low and has varied without trend since 1987 (Figure 81). An examination of the spring and fall U.S. RV surveys from the Gulf of Maine, during 1967-2006, indicates that, although there was a slight decline in abundance and biomass in the late 1960s, there has been little change in the trend since then (NEFSC, 2007).

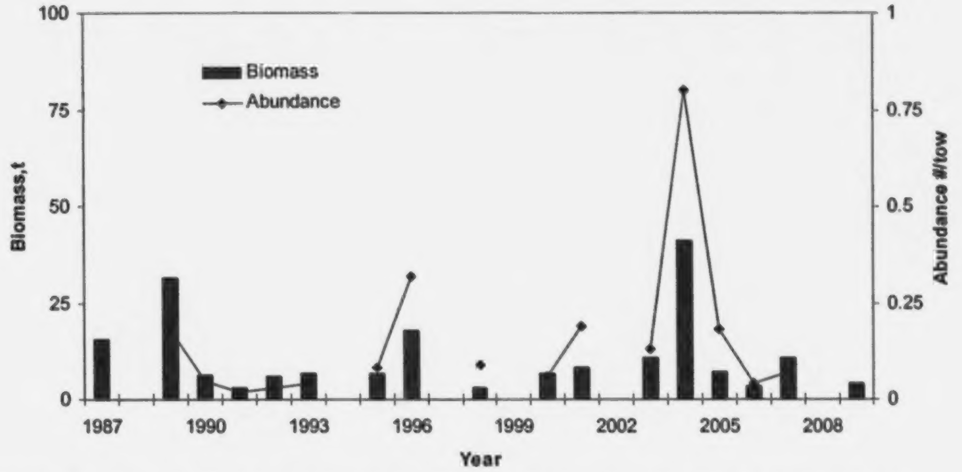


Figure 81. *Biomass (bars) and abundance (line) of Eastern Georges Bank smooth skate.*

Population Structure Relative to Moratorium Area

The fish that have been observed on the Northeast Peak from the Canadian and U.S. surveys are likely from the same population as fish in the deeper waters around the Bank (NEFSC, 2007).

Life History, Location, and Timing

The life history of smooth skate is not well understood (Packer et al., 2003d).

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that smooth skate may be vulnerable to operational discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Smooth skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.14.5 Barndoor Skate

Distribution, Habitat, Abundance, and Predator and Prey

Barndoor skate, *Dipturus laevis,* historically have ranged from the southern Grand Banks down to North Carolina, based on Canadian and U.S. RV survey data (Scott and Scott, 1988; McEachern, 2002). Recent analysis of Canadian RV surveys indicate the overall distribution of the species extends as far north as the Labrador Shelf up to depths of 1600 m (Gedamke et al., 2005). In recent years, they are most abundant from Georges Bank to the southern flanks of the Scotian Shelf and the Grand Banks (Simon et al., 2009). On Georges Bank, they are primarily restricted to the southern portion of the Bank on both the Canadian and U.S. sides of the international boundary (NEFSC, 2007) (Figure 82).

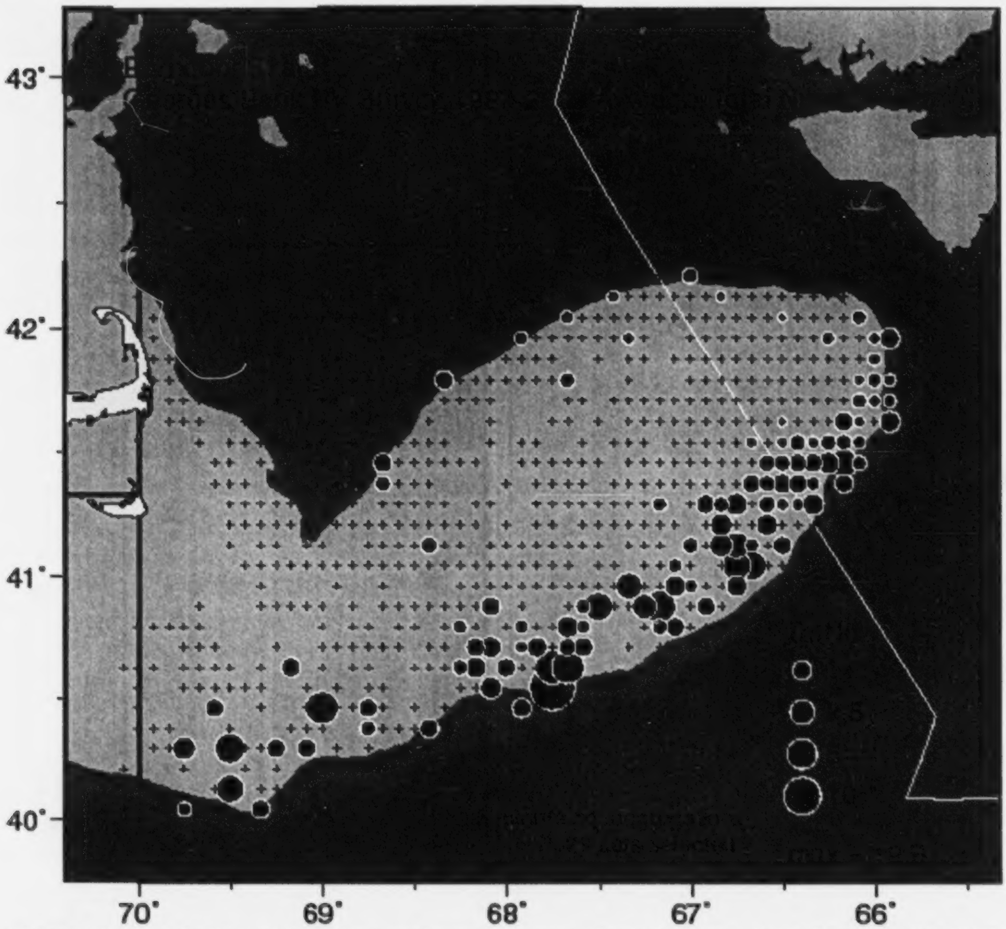


Figure 82. *Distribution of barndoor skate on Georges Bank from the DFO Georges Bank RV survey.*

Small barndoor skate (less than 70 cm) are predominately bottom feeders that primarily consume shrimp and crabs on Georges Bank. Larger barndoor skate consume primarily fish including sculpins, red hake, ocean pout, and herring (Packer et al., 2003e; Simon et al., 2009). The population biomass and abundance (number per tow) of Eastern Georges Bank barndoor skate, as calculated from the Canadian RV survey, has varied without trend since 1987 (Figure 83). An examination of the spring and fall U.S. RV surveys during 1963-2006 indicates that, when the entire survey area is considered, abundance was high in the 1960s and declined to very low levels in the 1970s to mid-1990s. Abundance has subsequently increased to estimates seen in the beginning of the survey. It is important to note that barndoor skate have been observed to be particularly adept at avoiding trawl gear, thus all estimates should be considered minimum estimates (Edwards, 1968).

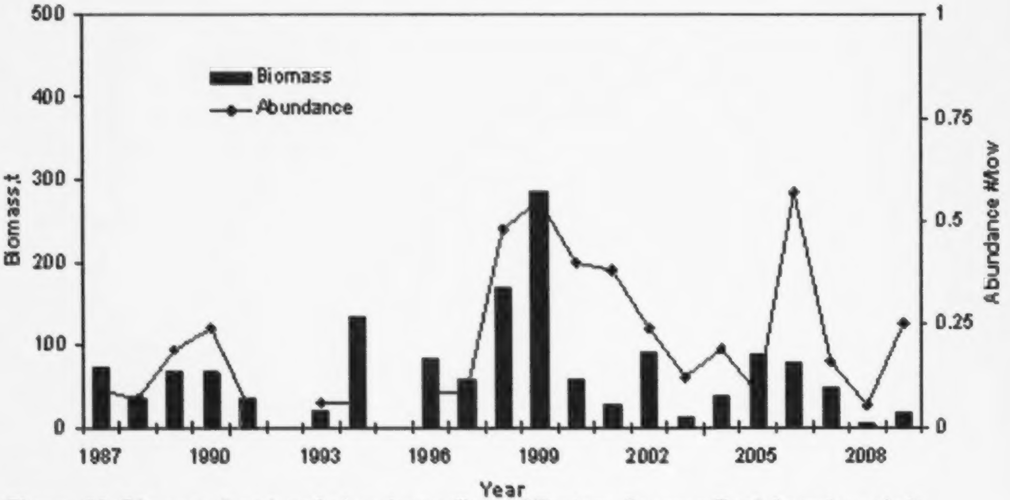


***Figure 83.** Biomass (bars) and abundance (line) of Eastern Georges Bank barndoor skate.*

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate some seasonal movement on the Bank, but no widescale migrations between Georges Bank and adjacent areas (NEFSC, 2007). Given the distribution of barndoor skate from the Canadian RV survey, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between barndoor skate on Georges Bank and the Scotian Shelf is unknown although, given the wide range of depths that the species has been observed, the Fundian Channel would not act as a barrier to the species.

Life History, Location, and Timing

Initial analyses on the extinction possibility of barndoor skate used life history characteristics from other skate species (Casey and Myers, 1998). A comprehensive analysis of these characteristics by Gedamke et al. (2005), from fish collected on Georges Bank, concluded that barndoor skate mature younger and grow more quickly than previously thought. Barndoor skate are 50% mature at 112 cm in length, at which time they are 6-7 years old. The Montreal Biodome reported on the growth and egg production from a barndoor skate maintained at their facility. Purses were laid throughout the year, with an incubation time of 343-494 days. Annual fecundity ranged from 70-115 (Parent et al., 2008). This estimate is much higher than had originally been estimated for the species.

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that barndoor skate may be vulnerable to operational discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses due to the length of time that it takes them to hatch and their sessile nature. The location of skate purses is unknown.

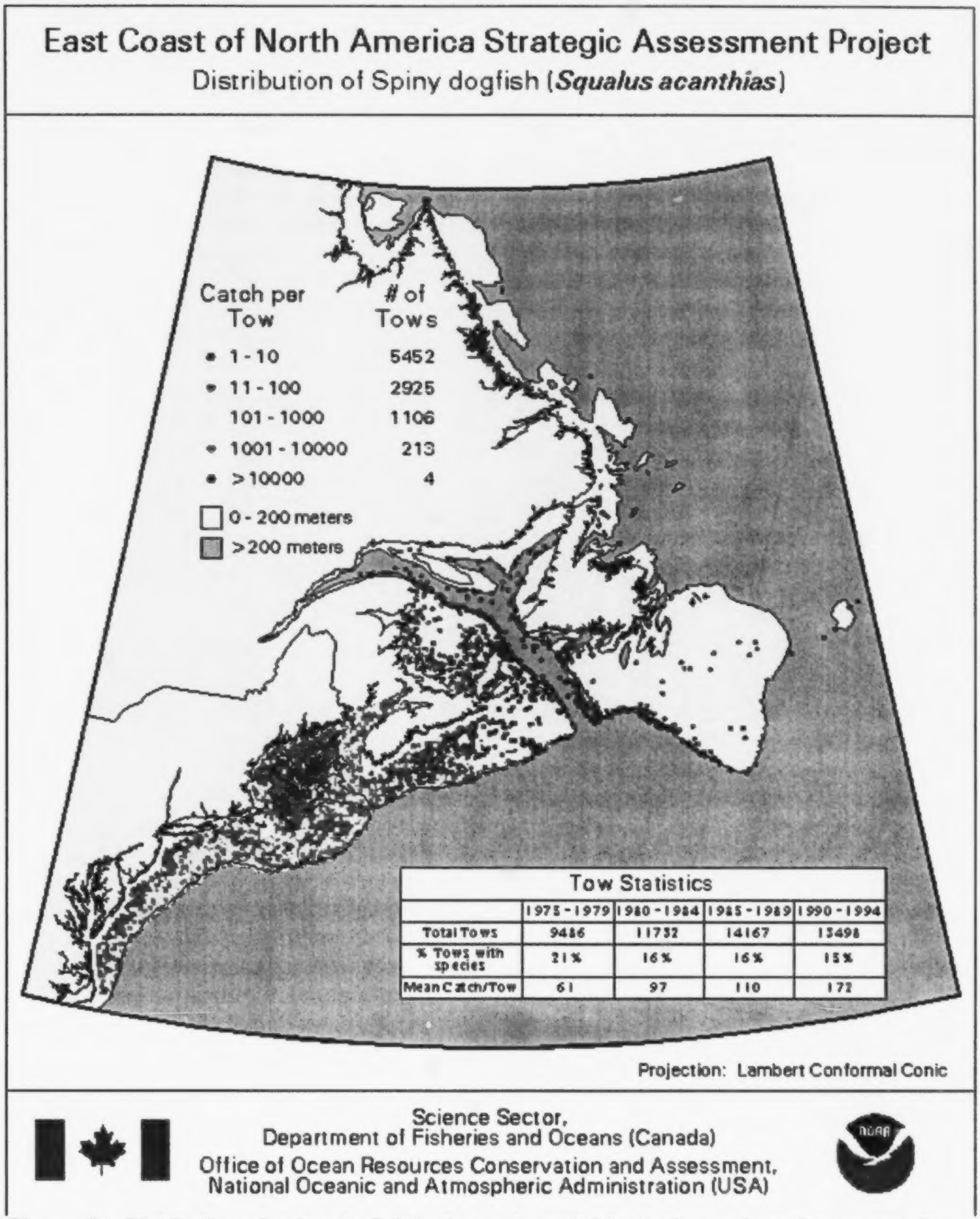
Status Designation

Barndoor skate is not listed pursuant to SARA and has not been evaluated by COSEWIC. The International Union for the Conservation of Nature (IUCN), however, concluded in 1994 that barndoor skate should be listed as 'vulnerable'. The U.S. National Marine Fisheries Service conducted an evaluation of the species in 1999 and concluded that there was no evidence that they were in danger of extinction or likely to become so in the near future. Nevertheless the IUCN reevaluated the status of the species in 2003 and listed the species as 'endangered' due, in part, to its life history characteristics.

9.15 SPINY DOGFISH

Distribution, Habitat, Abundance, and Predator and Prey

Spiny dogfish, *Squalus acanthias,* is a small squaloid shark common both on the bottom and in the water column of coastal temperate oceans around the world. In the northwest Atlantic, dogfish are most abundant from southern Newfoundland to North Carolina, although they can be found further north and south (Figure 84). In the northwest Atlantic, there appears to be be both migratory and resident dogfish populations. For the most part, dogfish tagged in the Canadian and U.S. waters have remained there. There is some movement, however, between Canadian and U.S. waters with the Gulf of Maine region being the primary mixing ground, supporting the view that there are several non-independent stock components. The primary factor affecting the seasonal inshore-offshore movements and coastal migrations may be water temperature (DFO, 2007a).


East Coast of North America Strategic Assessment Project
Distribution of Spiny dogfish (*Squalus acanthias*)
Catch per Tow
# of Tows
1-10 5452
11-100 2925
101-1000 1106
1001-10000 213
>10000 4
0-200 meters
>200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	21%	16%	16%	15%
Mean Catch/Tow	61	97	110	172

Figure 84. *Distribution of spiny dogfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

The spiny dogfish is an opportunistic feeder eating whatever prey is abundant. In general, their diet is comprised of small fishes such as capelin, cod, haddock, hake, herring, mackerel, and sand lance. They also eat invertebrates such as krill, crabs, polychaete worms, jellyfish, ctenophores, amphipods, squid, and octopus (Zwanenburg et al., 2006). There are currently no estimates of the absolute population abundance of spiny dogfish in the northwest Atlantic. Minimum estimates, however, indicate that the population increased from the early-1980s to the early-1990s to approximately 500,000 t and then declined to the present value of approximately 300,000 t (DFO, 2007b).

Population Structure Relative to Moratorium Area

The Gulf of Maine and Georges Bank has been suggested as an important mating ground for spiny dogfish sharks in the northwest Atlantic. Sexually mature and pregnant females were distributed throughout the waters of southwest Nova Scotia during the summer and fall and moved offshore to deeper waters in the winter. Pupping grounds have not been observed in Canadian waters, however, large aggregrations of mature females occur in deep warm waters off the edge of the contential shelf and in deep basins of the central shelf throughout their range. This suggests that pupping occurs in these deep offshore areas during the winter (DFO, 2007b).

Life History, Location, and Timing

This species is a relatively unproductive shark with a generation time of approximately 30 years. Males mature at 10 years while females mature at 16 years. They are thought to mate in winter, although the mating grounds in the North Atlantic remain unknown. After an extended gestation period of 18-22 months, an average of 5-6 pups are born during the winter months in the warmer waters off the edge of the continental shelf and in the deep basins of the central shelf throughout their range (North Carolina or New England).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses in the range of 25-200 Hz are broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. This and other studies listed in Myrberg (2001) indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns, as well as cause an increase in aggressive interactions between and/or among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound were on-going for several days, there is also the possibility that the hunting ability of the sharks in the area may be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals. In addition, the long gestation period, late age of sexual maturation, and slow growth rate for spiny dogfish makes the species susceptible to increased mortality from all sources including human activities.

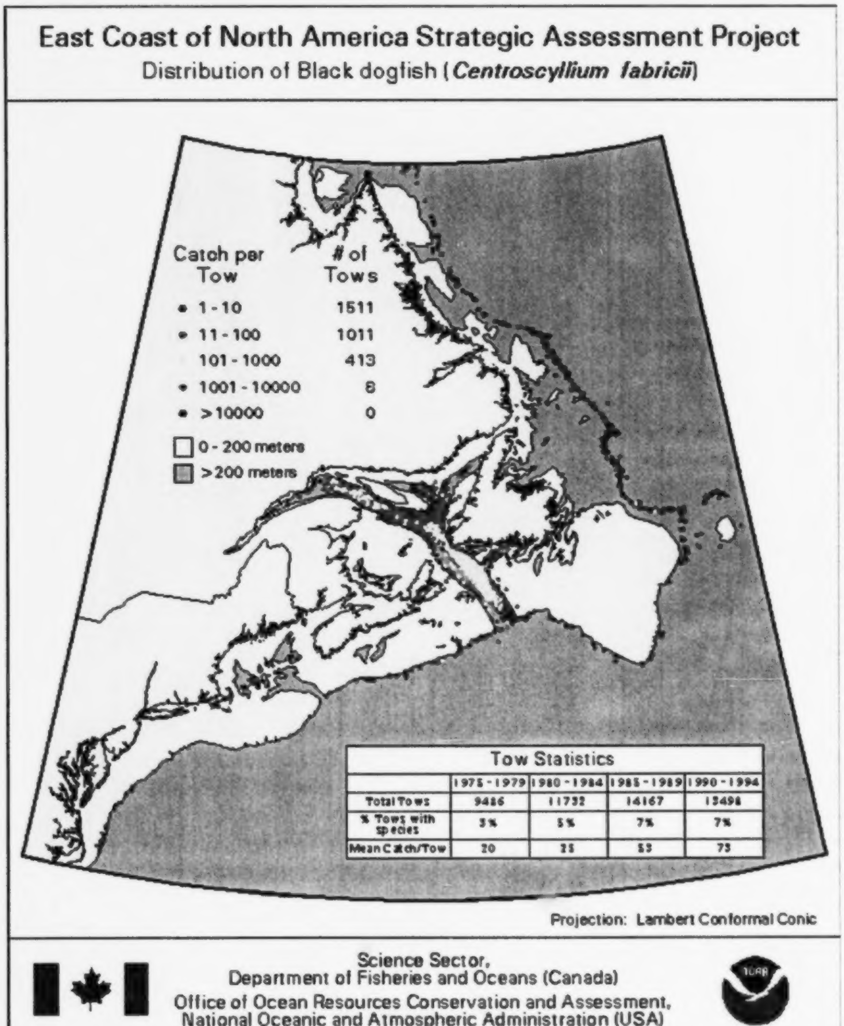
Status Designation

Spiny dogfish is not listed pursuant to SARA, although COSEWIC designated the species as 'special concern' in April 2010.

9.16 BLACK DOGFISH

Distribution, Habitat, Abundance, and Predator and Prey

The black dogfish, *Centroscyllium fabricii,* is a small, bottom-dwelling shark that sometimes forms large schools, which are possibly segregated by sex and size. It is a deepwater species found in temperate to boreal waters over the outer continental shelves and slopes of the North Atlantic Ocean. In the northwestern Atlantic it ranges from Greenland to North Carolina and possibly Florida (Figure 85). This species typically occurs at shallower depths in the northern part of its range (Kiraly et al., 2003). The diet of the back dogfish consists primarily of crustaceans, squids, cephalopods, jellyfish, and bony fishes (Kiraly et al., 2003). Information regarding its abundance remains unknown.


East Coast of North America Strategic Assessment Project
Distribution of Black dogfish (*Centroscyllium fabricii*)
Catch per Tow
# of Tows
1-10 1511
11-100 1011
101-1000 413
1001-10000 8
>10000 0
0-200 meters
>200 meters
Projection: Lambert Conformal Conic
Science Sector, Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment, National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	3%	5%	7%	7%
Mean Catch/Tow	20	25	53	73

Figure 85. *Distribution of black dogfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).*

Population Structure Relative to Moratorium Area

Information regarding the population structure and movement of black dogfish remains unknown.

Life History, Location, and Timing

There is little information on the reproductive biology of the this species. Black dogfish sharks reproduce throughtout the year without a well defined breeding or pupping season. The litter size ranges from 4-40 pups, with a mean of 16 (Yano, 1995).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses in the range of 25-200 Hz are broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. This and other studies listed in Myrberg (2001) indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns, as well as cause an increase in aggressive interactions between and/or among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound were on-going for several days, there is also the possibility that the hunting ability of the sharks in the area may be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Black dogfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17 LARGE PELAGICS

The shelf and slope waters of Georges Bank provide important foraging habitat for several large pelagic species (i.e. sharks, swordfish, and tunas) during their seasonal feeding migrations along the edge of the continental shelf. Six species of large sharks are regularly found on or around Georges Bank. These include porbeagle, thresher, basking, shortfin mako, blue, and smooth hammerhead sharks. White sharks are rare in Canadian waters, however, as it has been designated by COSEWIC as endangered, information on white shark is included here. Similarly, immature swordfish and bluefin tuna are attracted to Georges Bank during the summer to take advantage of the plentiful prey.

9.17.1 Swordfish

Distribution, Habitat, Abundance, and Predator and Prey

The broadbill swordfish, *Xiphias gladius*, is a pelagic species that is found in tropical and temperate seas throughout the world. They are distributed widely in the Atlantic Ocean and Mediterranean Sea from Newfoundland to Argentina in the western Atlantic. Swordfish migrate into Canadian waters in the summer as part of their annual seasonal movement, subsequent to spawning in subtropical and tropical locations from January-March (Figure 86). Swordfish swim throughout the water column and are known to move over a large depth range. While in Canadian waters, swordfish exhibit regular diving behaviour during the night followed by a period of daytime basking, which is thought to be a required warm-up period following extended periods of feeding in deeper, relatively cold waters (Beckett, 1972).

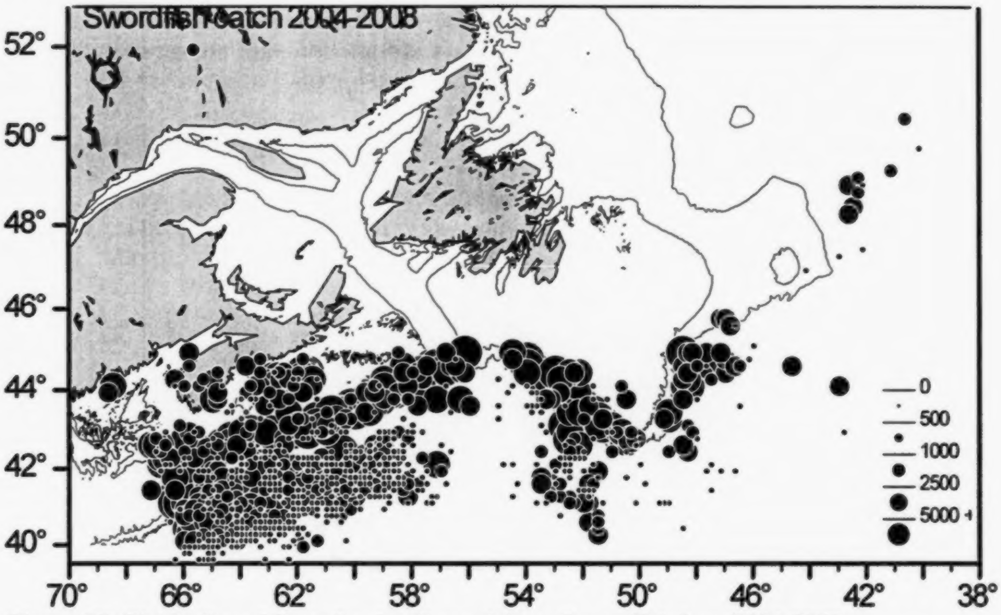
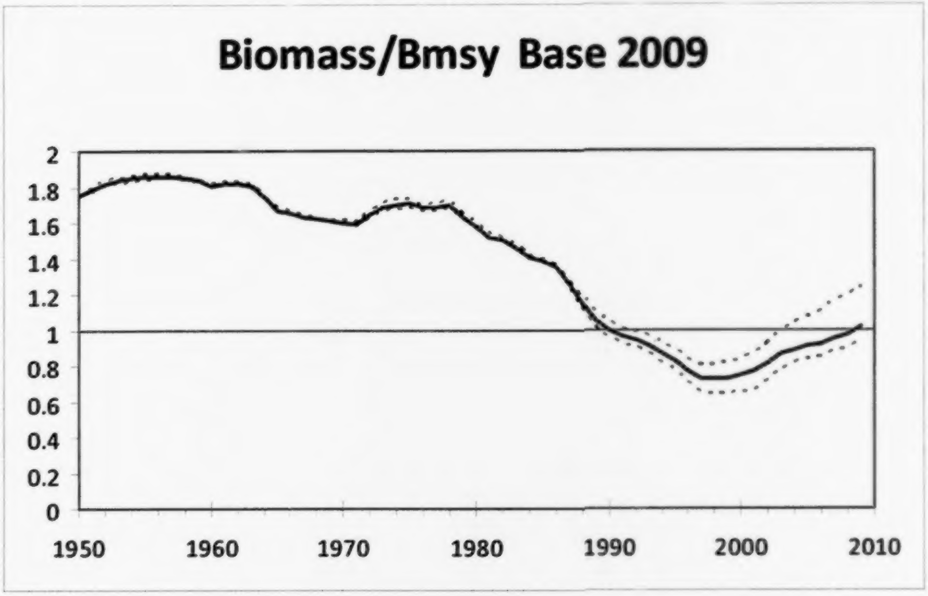


Figure 86. *Distribution of Canadian longline catches of swordfish from 2004-2008.*

Swordfish feed throughout the water column on a wide variety of prey, including groundfish, pelagic fish, and invertebrates. Stomach content analyses demonstrate that, on Georges Bank, swordfish experience high feeding success and forage on shortfin squid, barracudina, lantern fish, and silver hake (S. Smith, unpublished data). The Northeast Peak of Georges Bank is an important seasonal feeding area for Atlantic swordfish.

In 1999, the International Commission for the Conservation of Atlantic Tunas (ICCAT) established a rebuilding program for the over-exploited North Atlantic swordfish stock, with the intent of achieving appropriate stock and catch levels in 10 years (ICCAT, 2000). Due, in part, to good recruitment and low catch levels in recent years, the North Atlantic swordfish stock is considered rebuilt at the 2009 stock assessment. The estimated relative biomass trend shows a consistent increase since 2000 (Figure 87). The relative trend in fishing mortality demonstrates that the level of fishing peaked in 1995, followed by a decrease until 2002. There has been a small increase during the 2003-2005 period, with a downward trend since that time (ICCAT, 2009a).



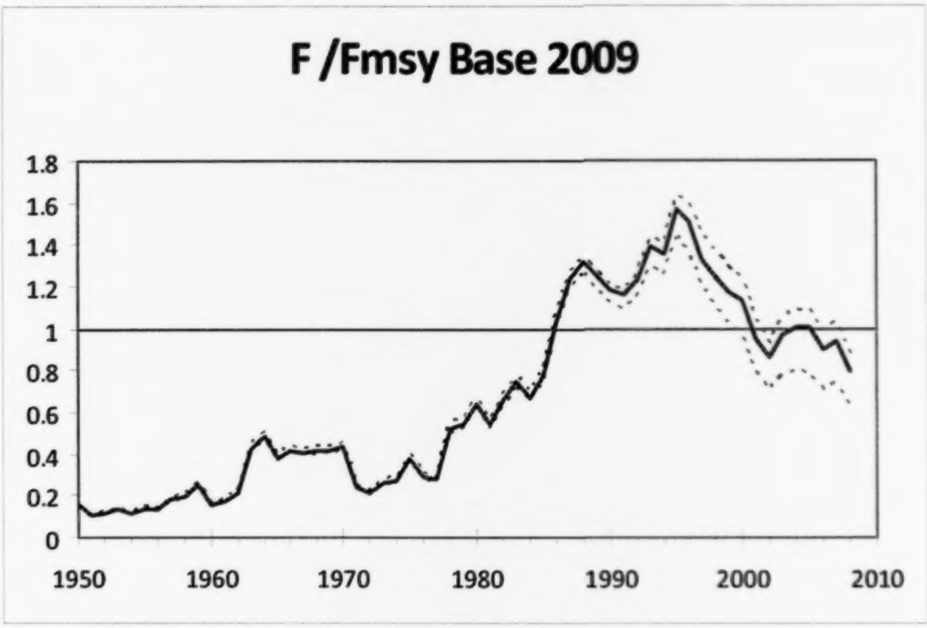


Figure 87. *Relative biomass (top) and relative fishing mortality (bottom) trends for North Atlantic swordfish. The solid lines represent point estimates and broken lines represent estimated 80% bias corrected confidence intervals.*

Population Structure Relative to Moratorium Area

Swordfish in the Atlantic Ocean are managed by ICCAT as three separate stocks: the North and South Atlantic stocks are separated at 5°N latitude, as well as the

Mediterranean stock. A recent workshop on stock structure (ICCAT, 2007) supported the division, and concluded that the assumptions concerning stock structure and management units were supported by swordfish genetic information presented at that time.

The Northeast Peak of Georges Bank is an important seasonal feeding area for Atlantic swordfish. Swordfish on Georges Bank tagged with pop-up satellite archival tags revealed a consistent pattern of movement, with individuals occupying waters north of 40°N from June-October, before migrating south to the Caribbean Sea where they remained until April (Neilson et al., 2009). The tagged fish consistently returned to Georges Bank the following June, providing strong evidence of precise homing to the summer foraging grounds.

Life History, Location, and Timing

Spawning in the Atlantic Ocean is believed to occur throughout the year at locations in a geographic band extending from 34°N (off the southeast coast of the U.S.) to 35°S latitude (off southeast Brazil) (Neilson et al., 2007).

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for swordfish, and there is strong evidence of annual homing behaviour. Activities that may disrupt the behaviour of large schools of prey species may cause swordfish to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Swordfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17.2 Bluefin Tuna

Distribution, Habitat, Abundance, and Predator and Prey

The Atlantic bluefin tuna, *Thunnus thynnus*, is a pelagic species distributed throughout the entire North Atlantic and its adjacent seas, primarily the Mediterranean Sea. It occupies the surface and subsurface waters of coastal and open sea areas between the surface and 200 m water depth. Bluefin tuna can maintain a broad range of temperatures, while preserving stable internal body temperatures. They frequently dive to great depths. They are known to form large schools and are highly migratory. Bluefin tuna migrate into Canadian waters in the summer, as part of their annual seasonal movement (Figure 88). Bluefin tuna are opportunistic feeders and, in general, juveniles feed on crustaceans, fish, and cephalopods, while adults primarily feed on fish such as herring, anchovy, sand lance, sardine, sprat, bluefish, and mackerel.

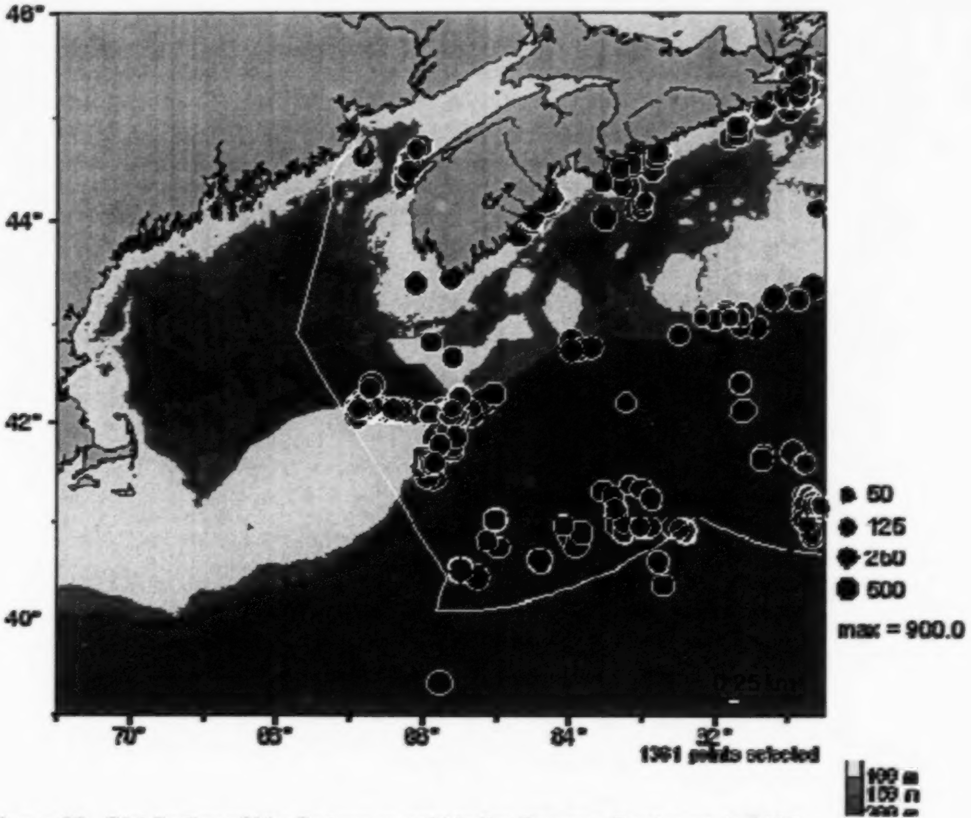


Figure 88. Distribution of bluefin tuna caught in the Georges Bank area in 2008.

In 1999, ICCAT considered the western Atlantic bluefin tuna stock to be over-exploited and consequently established a rebuilding plan with the intention of achieving appropriate stock and catch levels in twenty years (ICCAT, 1999). The 2009 update on stock status (ICCAT, 2009b) indicated that the Spawning Stock Biomass (SSB) of western Atlantic bluefin tuna declined steadily between the early 1970s and 1992. Since then, SSB has fluctuated between 18-27% of the 1975 level (Figure 89). An estimate of SSB in 2007 was 8,693 t, which is a decline of 82% of the 1970 SSB estimate of 49,482 t.

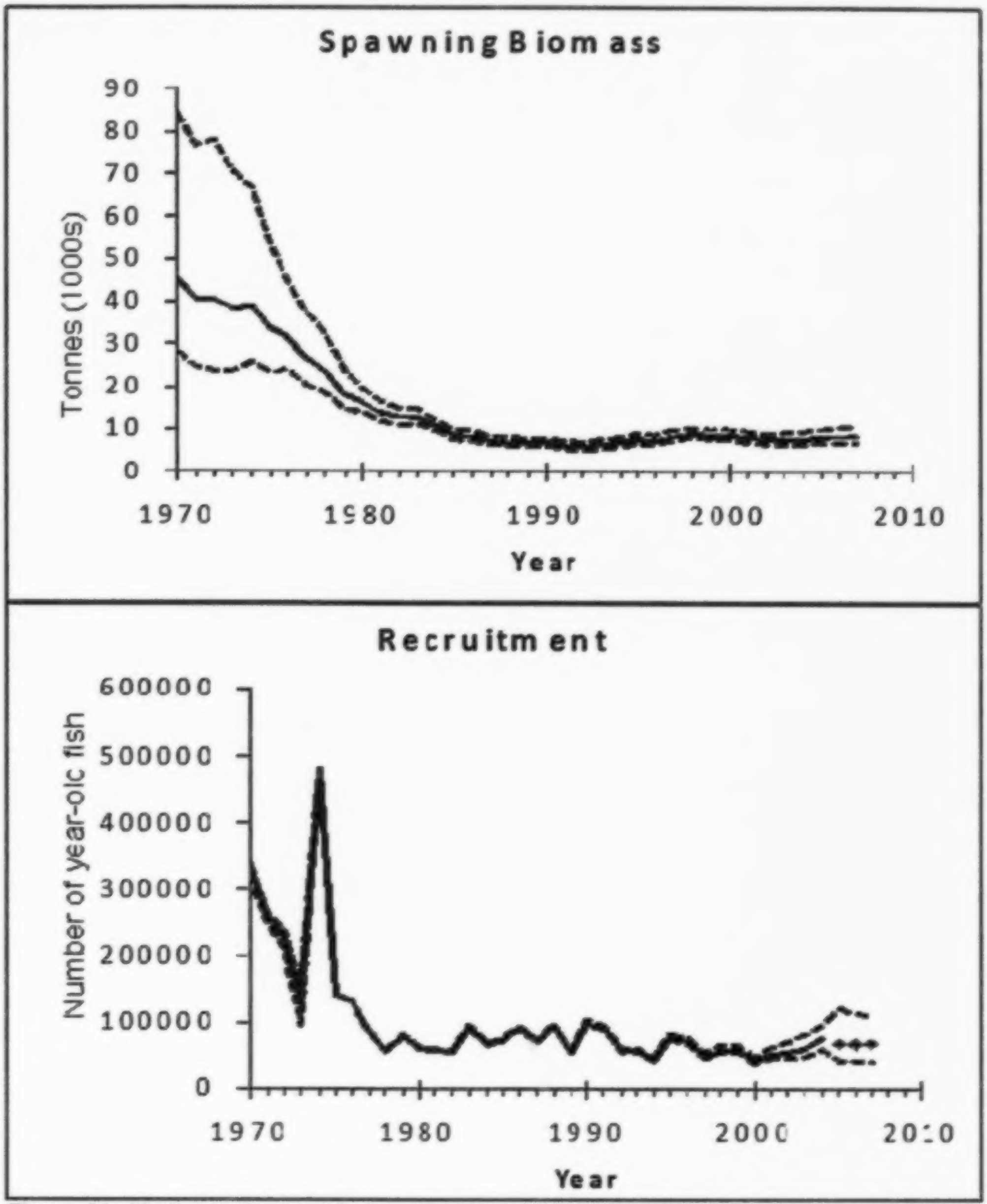


Figure 89. *Median estimates of spawning biomass (age 8+, top) and recruitment (bottom) for western Atlantic bluefin tuna. The 80% confidence intervals are indicated with dotted lines.*

The stock has experienced different levels of fishing mortality over time, depending on the size of fish targeted by various fleets. Fishing mortality on spawners (i.e. ages 8 and older) declined markedly from 2002-2007. Estimates of recruitment were very high in the early 1970s, and additional analyses involving longer catch and index series suggested that recruitment was also high during the 1960s. Since 1977, recruitment has varied from year to year without trend (Figure 89).

Population Structure Relative to Moratorium Area

Atlantic bluefin tuna are managed by ICCAT as two stocks: the western Atlantic and eastern Atlantic (including the Mediterranean). Bluefin tuna stock structure is complex and some mixing across the management boundary is known to occur (Lutcavage, 1999; Block et al., 2001; Block et al., 2005; Rooker et al., 2008; ICCAT, 2009b). Bluefin tuna enter Canadian waters in July and remain until November. Research on bluefin tuna migration using implantable archival tags demonstrates that Georges Bank is a high-use area by bluefin tuna, with movement onto the Bank in June-July and remaining throughout October-November (Walli et al., 2009). Golet (2010) has documented an eastern shift in position of large surface schools of bluefin tuna from the inshore Gulf of Maine to Georges Bank over a sixteen year period.

Life History, Location, and Timing

Maturity in bluefin tuna is reached at 8-12 years of age in the West Atlantic. The current understanding of bluefin tuna spawning in the western Atlantic is that it occurs in the Gulf of Mexico from April-June and, in the eastern Atlantic, spawning occurs in the Mediterranean Sea throughout the summer.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for bluefin tuna, and is a key habitat for obtaining seasonal energy requirements. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Bank area in search of alternate foraging habitat. Much of the ecology and stock structure of bluefin tuna remains unknown.

Status Designation

Bluefin tuna is not listed pursuant to SARA, although COSEWIC and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) have bluefin tuna under review and have scheduled their assessments for 2010.

9.17.3 Yellowfin Tuna

Distribution, Habitat, Abundance, and Predator and Prey

Yellowfin tuna, *Thunnus albacares*, is a pelagic species found in tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans. In the western Atlantic, they range from southern Canada to northern Argentina and, in the east, from the Netherlands to South Africa. Juvenile yellowfin tuna generally stay in coastal areas of the equatorial region, while pre-adults and adults are associated more with oceanic waters. Yellowfin tuna migrate into Canadian waters in the summer to feed (Figure 90).

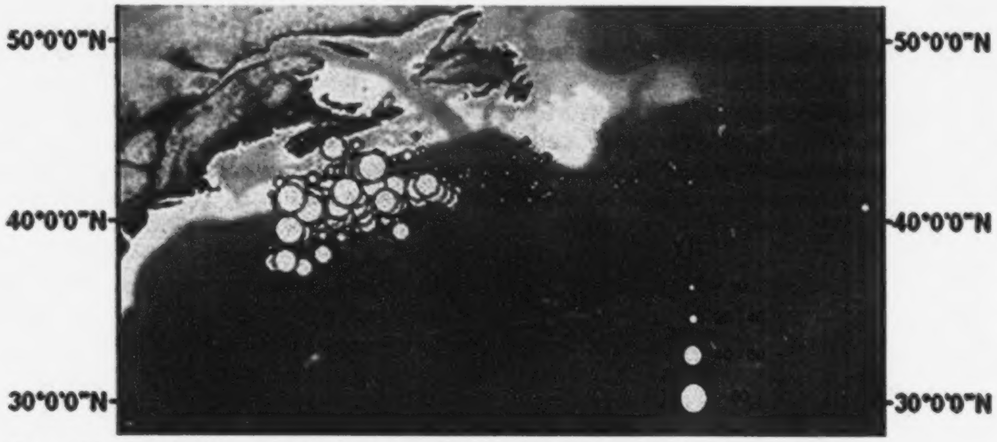


Figure 90. *Distribution of yellowfin tuna (Yft) caught by Canadian longline in 2008.*

Yellowfin tuna are opportunistic predators and feed on a broad range of prey types including fish and squid. The most recent stock assessment for Atlantic yellowfin tuna was conducted in 2008 (ICCAT, 2009c) (Figure 91). Although there is a fair level of uncertainty around the estimates of stock biomass and fishing mortality, they are estimated to be near levels that would support the maximum sustainable yield (MSY). Results indicate that maintaining current catch levels into the future would lead to a stock biomass somewhat above relative biomass, B_{MSY}.

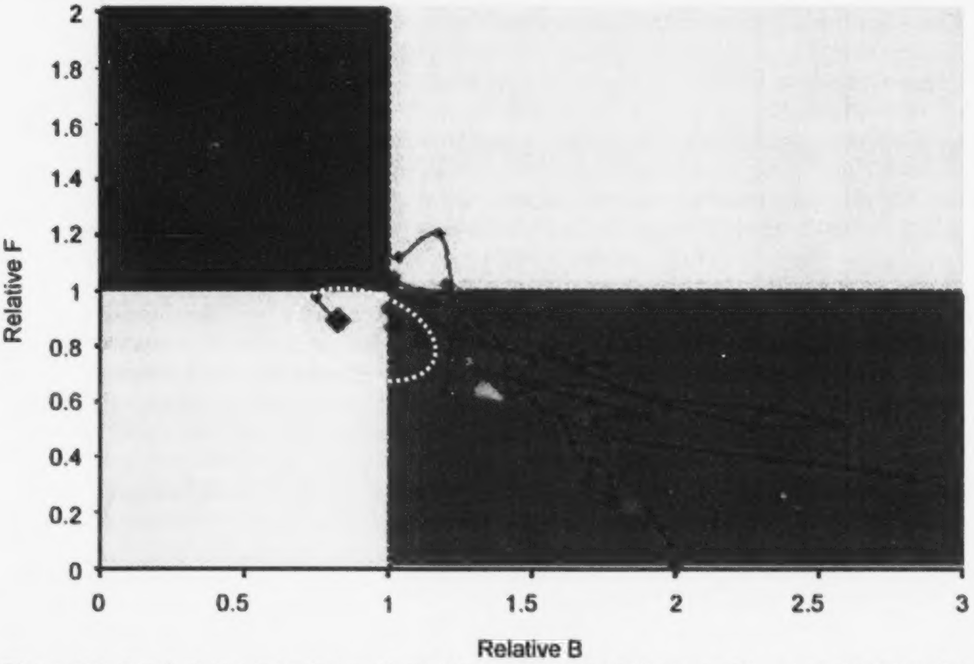


Figure 91. *Stock status trajectories of relative biomass (Relative B, or B/$_{BMSY}$) and relative fishing mortality (Relative F, or F/F_{MSY}) from three models: ASPIC (blue line); VPArun5 (red line); and VPArun10 (green line). Current status is indicated by the large point at the end of each time series (ICCAT, 2009d).*

Population Structure Relative to Moratorium Area

Yellowfin tuna are managed by ICCAT as a single Atlantic stock, based on the distribution of catches and marking studies. Transoceanic migrations are known to occur through marking studies. Yellowfin tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

Spawning occurs throughout the year in equatorial waters of the western and eastern Atlantic.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including yellowfin tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Yellowfin tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17.4 Bigeye Tuna

Distribution, Habitat, Abundance, and Predator and Prey

Bigeye tuna, *Thunnus obesis*, is a pelagic species found in tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans. In the western Atlantic, they range from southern Canada to northern Argentina and, in the east, from Ireland to South Africa. Young individuals typically inhabit equatorial waters, while adults migrate into northern latitudes. Bigeye tuna migrate into Canadian waters in the summer to feed (Figure 92).

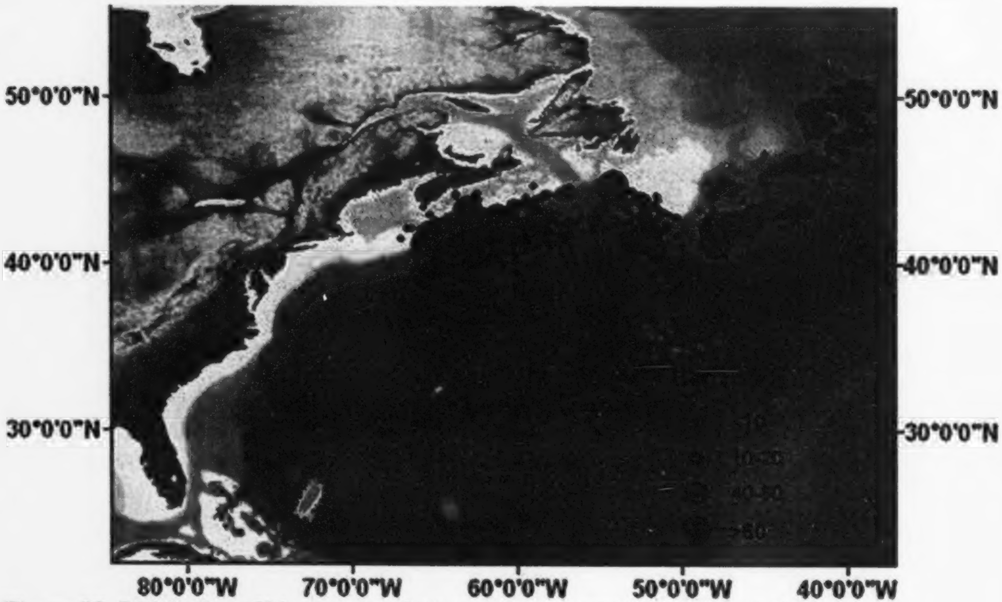


Figure 92. *Distribution of bigeye tuna (Bet) caught by Canadian longline in 2008.*

Bigeye tuna are opportunistic feeders and prey on pelagic fish, cephalopods, and euphausids. The most recent stock assessment for Atlantic bigeye tuna was conducted in 2004 (ICCAT, 2005). There was considerable uncertainty around the estimates due to lack of various types of information. Results indicated that high catches in the mid-1990s caused the stock to decline considerably (Figure 93). Since then, the decline leveled off as total catches decreased. The next stock assessment for bigeye tuna is scheduled for July 2010.

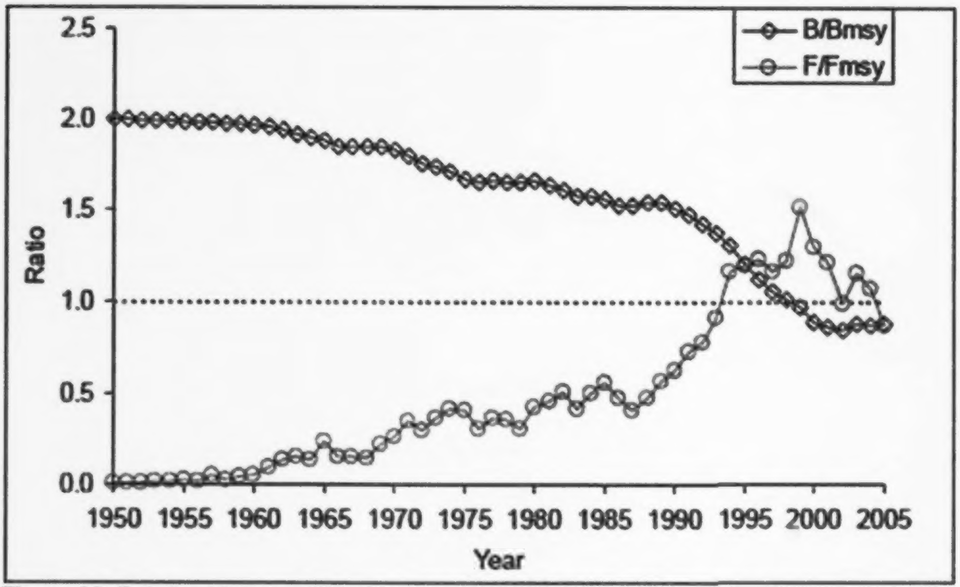


Figure 93. *Relative biomass (B/B$_{MSY}$) and relative fishing mortality (F/F$_{MSY}$) trajectories of Atlantic bigeye tuna.*

Population Structure Relative to Moratorium Area

Bigeye tuna are managed by ICCAT as a single Atlantic stock. Transatlantic migrations are known through marking studies to occur from the Gulf of Guinea to the central and eastern Atlantic Ocean (Pereira, 1995). Bigeye tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

Spawning occurs throughout the year in equatorial waters from the coast of Brazil to the Gulf of Guinea.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including bigeye tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Bigeye tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17.5 Albacore Tuna

Distribution, Habitat, Abundance, Predator and Prey

Albacore tuna, *Thunnus alalunga*, is a pelagic species distributed throughout the world in temperate and tropical seas. In the western Atlantic, they range from Nova Scotia to northern Argentina and, in the east, from Ireland to South Africa. Albacore tuna prefer cooler water temperatures and migrate into Canadian waters in the summer to feed (Figure 94).

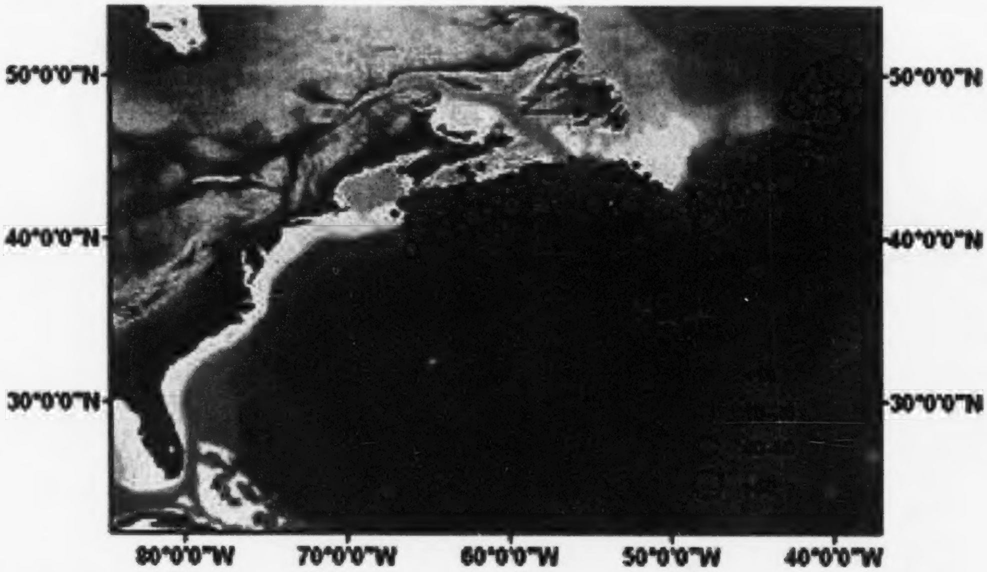


Figure 94. *Distribution of albacore tuna (Alb) caught by Canadian longline in 2008.*

Albacore opportunistically prey on schooling stocks of sardine, anchovy, mackerel, squid and, to a lesser extent, crustaceans. Spawning stock size has declined and in 2005 was about one quarter of the peak levels estimated for the late 1940s. Estimates of recruitment to the fishery, although variable, have shown generally higher levels in the 1960s and earlier periods, with a declining trend thereafter until 2004. The most recent assessment by ICCAT of North Atlantic Albacore stock occurred in 2009 (ICCAT, 2009e). Spawning stock biomass is expected to decline from the levels estimated in 2005 over the next few years, particularly given the fact that the 2006 catch was higher than the 2005 level. The spawning stock response to different catch levels after the next few years depends upon the strength of the 2003 year-class (Figure 95).

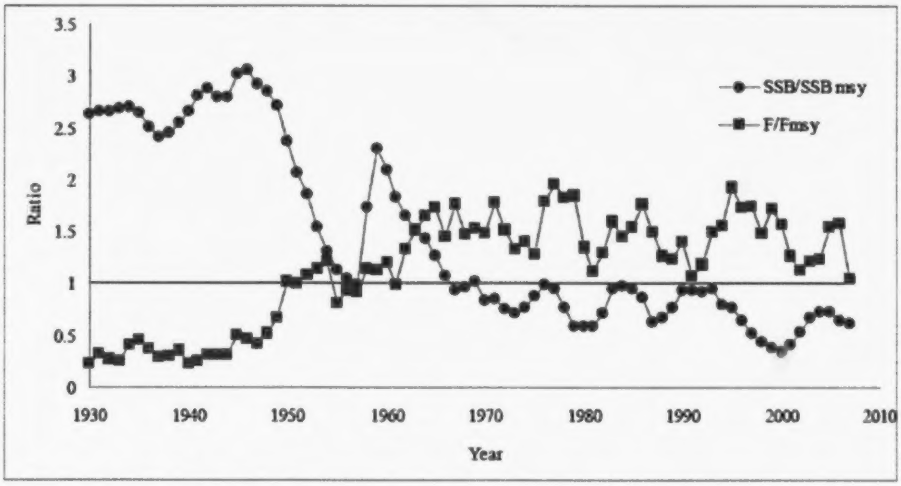


Figure 95. *Relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) trajectories of northern albacore.*

Population Structure Relative to Moratorium Area

Albacore tuna are managed by ICCAT as three stocks: the north and south Atlantic (divided at 5°N), as well as the Mediterranean. Although migration routes are still uncertain, Albacore tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

In the North Atlantic, albacore are considered mature around 90 cm in length or 5 years of age. Spawning occurs from April-September in waters offshore Venezuela, the Sargassum Sea (Le Gall, 1974; Nishikawa et al., 1985) and Gulf of Mexico (Richards, 1969; Richards, 1984).

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including albacore tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Albacore tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17.6 Porbeagle Shark

Distribution, Habitat, Abundance, and Predator and Prey

Porbeagle shark, *Lamna nasus*, is a wide-ranging coastal and oceanic shark that is the only representative of its genus in the North Atlantic. It is a cold-temperate pelagic species that occurs on both sides of the Atlantic, as well as in the south Pacific and Indian Oceans. In the western North Atlantic, the species range extends from Newfoundland to New Jersey, and possibly to South Carolina (Cassoff et al., 2007). Tagging studies indicate that only one stock resides in the northwest Atlantic, migrating between the Gulf of Maine and southern Newfoundland on an annual basis (Figure 96).

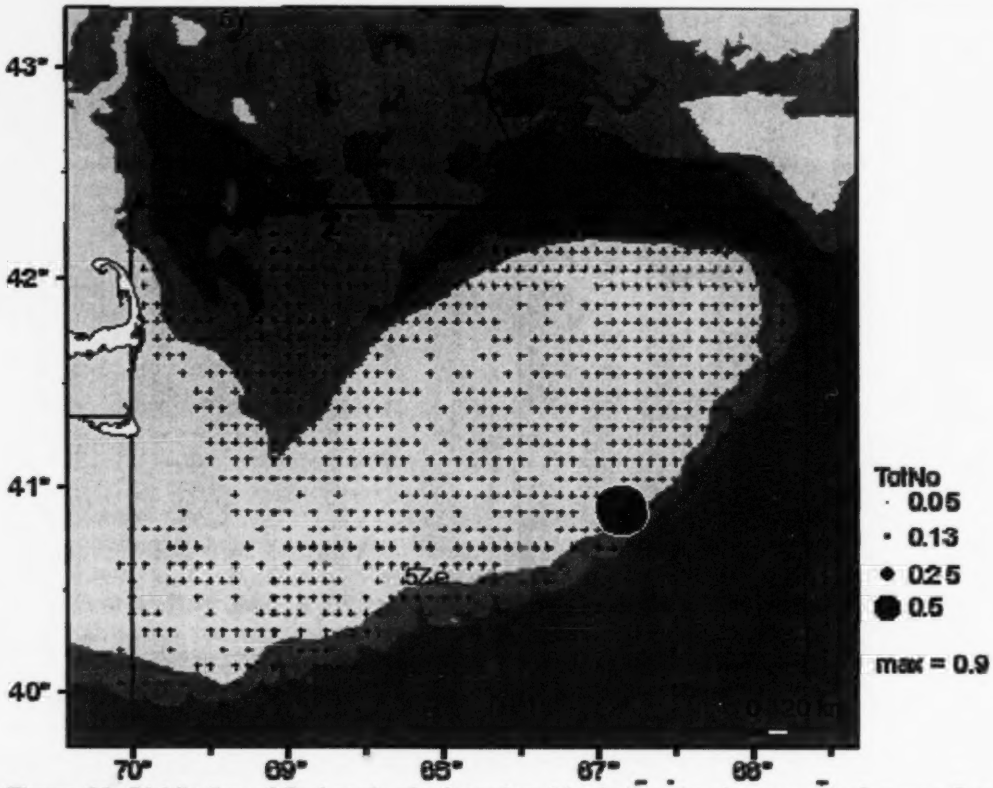


Figure 96. *Distribution of Porbeagle shark captured by bottom trawl surveys in Georges Bank area from 1986-2008.*

Porbeagle sharks move onto the Scotian Shelf in the early spring and into the Gulf of St. Lawrence and on to the Grand Banks during the summer and fall (DFO, 2002d). The primary factor affecting the distribution and habitat is thought to be temperature, with the species typically inhabiting water between 5-10 °C. It is primarily an opportunistic piscivore with a diet characterized by a wide range of species. Their diet mainly consists of pelagic fishes, such as herring, lancetfish, and mackerel, however, they also eat cod, redfish, haddock, squid, and shellfish (Joyce et al., 2002).

The abundance of porbeagle shark sharply declined after the fishery of foreign longliners began in 1961, recovering only partially until Canada entered the fishery in the 1990s. Abundance declined again, but stabilized in the late 1990s after the catch quotas were reduced. In 2004, the abundance of the northwest Atlantic population was estimated at approximately 4400 t, which corresponded to 11% of the virgin population of 1961 (DFO, 2005). Current population abundance is about 25% of the virgin population (Campana et al., 2010). Very low catch quotas and closure of the mating grounds off southern Newfoundland have allowed the population to begin to recover.

Population Structure Relative to Moratorium Area

Porbeagle sharks primarily migrate over the Georges Bank as part of their annual migration north; however, the Bank has been suggested as an important mating ground for porbeagle sharks in the northwest Atlantic. Mature female porbeagles congregate on

Georges Bank in June in preparation for mating, and then disperse to other waters once mating is complete. The pupping ground location lies off the continental shelf in oceanic waters.

Life History, Location, and Timing

The porbeagle has a low fecundity, late age at sexual maturation, and low natural mortality. In the northwest Atlantic, mating occurs on the Grand Banks, south of Newfoundland, and at the mouth of the Gulf of St. Lawrence (COSEWIC, 2004). Porbeagle sharks move south and possibly into deeper water in late-fall, although their winter distribution is unknown (Zwanenburg et al., 2006). Age at maturity is approximately 8 years in males and 13 years in females. The reproductive cycle appears to last one year. After a fall mating period (September–November), females give birth to an average of 4 young in spring (April–June). The porbeagle shark life span is estimated to be between 25-46 years, with a generation time of approximately 18 years (Jensen et al., 2002).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Porbeagle shark is not listed pursuant to SARA, although COSEWIC designated it as 'endangered' in May 2004.

9.17.7 Thresher Shark

Distribution, Habitat, Abundance, and Predator and Prey

The thresher shark, *Alopias vulpinus*, is a pelagic species that inhabits both coastal and oceanic waters worldwide. It is most common in warm temperate waters of the eastern and western Atlantic Ocean and tropical seas, but can also be found in cold temperate waters. In the northwest Atlantic Ocean, it ranges from Newfoundland to Cuba. Adults are most abundant over continental and insular shelves and slopes, while juveniles reside in coastal bays and near shore waters. This species is often associated with areas characterized by high biological productivity, such as strong frontal zones near regions of upwelling (Fowler et al., 2005).

Thresher sharks feed primarily on small, pelagic schooling fish, such as mackerel, herring, juvenile tuna, bluefish, needlefish, lancetfish, lanternfish, menhaden, and shad, as well as crustaceans, squids, octopi and, very rarely, seabirds (Fowler et al., 2005). There are few population analyses available for thresher sharks, as reliable, species-specific catch and discard data are not available. An analysis of logbook data from the pelagic longline fleets targeting swordfish and tunas in the northwest Atlantic indicates that thresher sharks have declined by more than 75% from 1986-2000 (Baum et al., 2003; Fowler et al., 2005). There is no estimate of abundance after this period.

Population Structure Relative to Moratorium Area

Information regarding the stock structure of the thresher shark in the Georges Bank area remains unknown. The common thresher is migratory, moving to higher latitudes following warm water masses. Thresher sharks are sited in Canadian waters during the summer months, occurring most frequently in Georges Bank waters from August to Septmeber.

Life History, Location, and Timing

No distinct breeding season is observed for thresher sharks and the spawning grounds for the species is unknown. The gestation period is reported to be nine months, with litters of 2-7 pups born during the spring. Thresher sharks reach maturity between 3-8 years old. They are estimated to live up to 45-50 years (Fowler et al., 2005).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Thresher shark is not listed as an at-risk species pursuant to SARA and has not been evaluated by COSEWIC.

9.17.8 Basking Shark

Distribution, Habitat, Abundance, and Predator and Prey

Basking sharks, *Cetorhinus maximus*, are found circum-globally in temperate coastal shelf waters. Basking sharks move seasonally and are widely distributed in the North Atlantic Ocean (Gulf of St. Lawrence, Southern Newfoundland, Scotian Shelf, and Gulf of Maine) during the summer and migrate to southern U.S. waters and tropical waters in the winter. Water temperature may set a limit for the range of the basking shark, as they appear to be restricted to temperatures higher than 6 °C (DFO, 2008d).

Basking sharks are very large, slow-moving planktonic feeders with a diet that primarily consists of copepods and other zooplankton, fish eggs, and larvae. Existing fish surveys do not provide an abundance index for basking sharks. An annual index derived from surveys for right whales in the Bay of Fundy indicated a sharp increase in abundance in the 1990s followed by an equally abrupt decline by 2000. The decrease, however, was likely due to changes in distribution rather than mortality. Results of a population model indicate that the population has decreased, although sightings per unit effort indices in the U.S. show no evidence of a decline since 1979 (DFO, 2008d).

Population Structure Relative to Moratorium Area

Basking sharks often feed in the waters around Georges Bank each summer and fall. They also form mating aggregations each summer, some of which may occur in and around the Georges Bank area (DFO, 2008d).

Life History, Location, and Timing

Breeding has not been observed, but putative mating aggregations have been observed in June off the coast of Nova Scotia. Basking sharks give birth to an average of 6 pups during the summer, after a gestation period of 2-3 years (Zwanenburg et al., 2006). The winter distribution of most populations and locations used by pregnant females are unknown, although it is likely that wintering sharks occur mainly in deep shelf water (Fowler et al., 2005). The Emerald Basin on the Scotian Shelf is suspected to be a mating area for the populations, although the pupping area remains unknown (DFO, 2008d).

Known Vulnerabilities

The life history characteristics of basking shark, including late maturity, long gestation period, and low fecundity, render this species particularly vulnerable. In addition, patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Basking shark is not listed as an at-risk species pursuant to SARA, although the Atlantic population was designated as 'special concern' by COSEWIC in November 2009. In addition, basking sharks have been listed under Appendix 2 of CITES and listed by IUCN as 'vulnerable' globally and 'endangered' in the northeast Atlantic.

9.17.9 Shortfin Mako Shark

Distribution, Habitat, Abundance, and Predator and Prey

Shortfin mako shark, *Isurus oxyrinchus*, is circum-global in temperate and tropical waters. Individuals found in Atlantic Canada represent the northern extension of their range.

The shortfin mako shark feeds mainly upon bony fishes, including bluefish, mackerels, tunas, bonitos, and swordfish, but they may also eat other sharks, porpoises, other marine mammals, sea turtles, and squid (DFO, 2004b). Although there is no decline in an indicator of status for the portion of the species that is in Atlantic Canada, two separate analyses suggest recent declines in the North Atlantic as a whole (40% from 1986-2001 and 50% from 1971-2003). The shark's population abundance in the North Atlantic has declined since the 1970s, but has been relatively stable since the late 1980s with trends in median size indicating a decline in the abundance of larger shortfin makos since 1998 (DFO 2006c).

Population Structure Relative to Moratorium Area

Shortfin mako shark migrate to the Atlantic coast of Canada generally in the late summer and fall, where they are usually associated with the warm waters of the Gulf Stream. Individuals found in Atlantic Canada are considered part of a larger North Atlantic population. There does not appear to be any reason to assume that the 'Canadian Atlantic population' is demographically or genetically independent from the larger Atlantic population, so the status of the species in Atlantic Canada should reflect the status throughout the North Atlantic (DFO, 2006b).

Life History, Location, and Timing

The life cycle of shortfin mako is not completely known. Males mature at 7-9 years, while females mature at approximately 17 years. Litters of 4-25 pups are born in late-winter to mid-spring after a gestation period of approximately 15-18 months and a reproductive cycle of 3 years. The larger females give birth to more and larger pups (COSEWIC, 2006a; Fowler et al., 2005). It is hypothesized that shortfin makos in the western North Atlantic are born far offshore to protect the young from predation, mostly by other sharks

(Schrey and Heist, 2003). The minimum lifespan has been estimated at 24 years, with a maximum life expectancy of up to 45 years.

Known Vulnerabilities

As a large (maximum length 4.2 m), relatively late-maturing (7-8 years) pelagic shark, shortfin mako has life history characteristics that make it particularly susceptible to increased mortality from all sources, including human activities. Bycatch from fishing activities in the North Atlantic is thought to be the most significant source of mortality for the population (Baum et al., 2003; DFO, 2006c).

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

The shortfin mako shark is being considered for listing pursuant to SARA. It was designated as 'threatened' by COSEWIC in April 2006.

9.17.10 Blue Shark

Distribution, Habitat, Abundance, and Predator and Prey

Blue shark, *Prionace glauca*, is considered to have a single highly-migratory population in the North Atlantic, of which a portion is present in Canadian waters seasonally. The blue shark is probably the most widely distributed of all shark species, occurring throughout tropical, sub-tropical, and temperate waters of the Atlantic, Pacific, and Indian Oceans. In the western Atlantic, its range extends from Newfoundland to Argentina and has been recorded from Georges and Browns Bank, along the continental shelf of Nova Scotia, the Grand Banks, and into the Gulf of St. Lawrence, in Atlantic Canada. Tagging studies indicate that the stock area may include the entire north Atlantic and that a clockwise migration occurs around this area (DFO, 1996b).

The diet of blue shark consists mainly of pelagic fish (herring, silver hake, red hake, mackerel, butterfish, tuna, and swordfish), demersal fish (cod, haddock, pollock, white hake, and sea raven), and cephalopods, particularly squid. Invertebrates (mainly pelagic crustaceans), small sharks, cetaceans (possibly carrion), and seabirds may also be eaten (DFO, 1996b).

An abundance index that is considered to best represent the portion of the population in the northwest Atlantic has declined 60% from 1986-2000. A second index shows no long-term trend for the whole population from 1971-2003. Indices of abundance in and near Canadian waters show variable trends, from no decline to 60% decline from the 1980s to early 2000s. There is evidence for a decline in mean length in longline fisheries in Canadian waters from 1986-2003 (COSEWIC, 2006b).

Population Structure Relative to Moratorium Area

Distribution and movement of this species is strongly influenced by seasonal variations in water temperature, reproductive condition, and availability of prey. Tagging studies of blue sharks have demonstrated extensive movements of blue sharks in the Atlantic, with numerous trans-Atlantic migrations that are probably accomplished by swimming slowly and utilizing the major current systems. Major oceanic migrations are associated with mating areas in the northwestern Atlantic (DFO, 2002d). From May through October, the blue shark is common offshore from the outer edge of the continental shelf, Georges Bank, to the Grand Banks, but they move south and offshore in the summer and fall (Kohler et al., 2002).

Life History, Location, and Timing

This species is a relatively productive shark (maximum age 16-20 years that mature at 4-6 years, generation time of 8 years, and 25-50 pups every two years). In the northwestern Atlantic, mating appears to be most frequent on the continental shelf from spring to early summer. After copulation, they move offshore where the sperm is stored for periods of months to years waiting for ovulation (Pratt, 1979). After fertilization, gestation is between 9-12 months. Birth has been observed over a wide seasonal range, from spring to fall, suggesting considerable variation amongst individuals.

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Blue shark is being considered for listing pursuant to SARA. It was designated as 'special concern' by COSEWIC in April 2006.

9.17.11 Smooth Hammerhead Shark

Distribution, Habitat, Abundance, and Predator and Prey

The smooth hammerhead shark, *Sphyma zygaena,* is a migratory species that is distributed worldwide. In the western Atlantic, the smooth hammerhead shark ranges from Nova Scotia in the summer to Florida in the winter (Casper et al., 2005). It is uncommon in the Georges Bank area. The smooth hammerhead shark prefers inshore waters over continental shelves or in bays and estuaries. They may also be found in the offshore in deeper waters over the continental shelf particularly when migrating.

The smooth hammerhead shark is an active-swimming predator that feeds on bony fishes, such as herring and menhaden, rays, skates, sharks (including of its own species), cephalopods and, to a lesser extent, crustaceans such as shrimp and crabs (Casper et al., 2005). Species-specific population trends for hammerheads are rarely available because of the amalgamation of catch data and species misidentification. Analysis of logbook data indicated that hammerhead sharks (grouped data for *S. lewini, S. mokarran* and *S. zygaena*) have declined in abundance by 89% since 1986 (Baum et al., 2003).

Population Structure Relative to Moratorium Area

During summer months, smooth hammerheads sometimes form schools during migrations northward to cooler waters, which is later followed by a return south in the winter. Hammerhead sharks are uncommon in the Georges Bank area, although sightings have been reported on the northeast tip of the Bank.

Life History, Location, and Timing

Individuals become sexually mature at 2.3 meters in length, although the age of maturity remains unknown. During the summer months, a litter of 20-40 pups are born following a 10-11 month gestation period.

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Smooth hammerhead shark is not listed pursuant to SARA and has not been evaluated by COSEWIC.

9.17.12 White Shark

Distribution, Habitat, Abundance, and Predator and Prey

The white shark, *Carcharodon carcharias,* has a global distribution but is quite rare in the North Atlantic. It is most frequently observed in inshore waters of the western North Atlantic, Mediterranean Sea, southern Africa, Australia, New Zealand, and the eastern North Pacific. It is absent from cold polar waters, hence, Atlantic and Pacific populations in Canada are isolated from each other. This very large apex predator is rare in most parts of its range, but particularly so in Canadian waters, which represent the northern fringe of its distribution. In Atlantic Canada, there have been 32 records since 1874.

White sharks are carnivorous and primarily eat fish (including rays, tuna, and smaller sharks), dolphins, porpoises, whale carcasses, and pinnipeds such as seals, fur seals and sea lions, and sometimes sea turtles (COSEWIC, 2006c). No abundance trend information is available for white sharks in Atlantic Canada. Numbers have been estimated to have declined by about 80% over 14 years (less than one generation) in areas of the northwest Atlantic Ocean outside of Canadian waters.

Population Structure Relative to Moratorium Area

The species is highly mobile and individuals in Atlantic Canada are likely seasonal migrants belonging to a widespread northwest Atlantic population, hence, the status of the Atlantic Canadian population is considered to be the same as that of the broader population (Baum et al., 2003; DFO, 2006d).

Clustering of white shark records in Atlantic Canada during late summer months suggests that they may be correlated with the seasonal shift of the warm Gulf Stream toward the coast.

Life History, Location, and Timing

Due to the rarity of this species, knowledge of the reproduction and life history of the white shark is incomplete. White sharks are slow growing and have a relatively long life span (23-60 years). Males reach sexual maturity at an age of 8-10 years and females reach maturity at an age of 12-18 years. White sharks have a gestation period of approximately 14 months, with females giving birth to an average of 7 pups believed to occur during the spring to late summer in warm-temperate coastal waters (COSEWIC, 2006c; Fowler et al., 2005). Possible white shark pupping areas on the east coast of North America include the Mid-Atlantic Bight (COSEWIC, 2006c).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies oultlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Blue shark is being considered for listing pursuant to SARA. It was designated as 'endangered' by COSEWIC in April 2006.

10.0 MARINE MAMMALS

10.1 CETACEANS

There are approximately 23 species of cetaceans (i.e. whales and dolphins) found on or around Georges Bank, however, only a subset of these are abundant seasonally and the Canadian Georges Bank moratorium lands do not represent the core distribution for any of them (CETAP, 1982; Waring et al., 2009). Although the range of each of these species is far broader than the boundaries of the Georges Bank moratorium area, the continental shelf edge and the region around the eastern end of the Bank represents a highly-utilized habitat area for cetaceans (Kenney and Winn, 1986).

High use areas for planktivores (e.g. right whale and sei whale) are concentrated in the western Gulf of Maine and the southwestern and eastern portions of the Bank. High use areas for teuthivores (squid-eaters) (e.g. sperm whale and pilot whale) are concentrated along the edge of the shelf (Kenney and Winn, 1986). Table 3 highlights the more common whales in the area, as well as their relative seasonal abundance. Katona et al. (1993), Kenney et al. (1997), and Whitehead et al. (1998) have reviewed the preferred habitat, residence time, distribution, and diet of the most common species of cetaceans found on Georges Bank, as well as the significance of the area to them. Select marine mammal species are summarized in the Appendix.

Table 3. *Seasonal abundance of cetaceans commonly found on Georges Bank. The symbols +, ++, and +++ refer to low, medium, and high abundance, respectively (adapted from Kenney et al., 1997).*

Species	Season			
	Winter	Spring	Summer	Fall
N.A. Right whale		+	++	+
Fin whale	+	++	+	+
Sei whale	+	++	+	+
Minke whale		+++	+	
Humpback whale		+	+	+
Sperm whale	+	+	++	+
Northern bottlenose whale		+		
Beaked whales (*Mesoplodon spp.*)		+	+	+
Blue whale		+	+	
Pilot whales	+	+++	+++	+
Risso's dolphin		+	++	++
Bottlenose dolphin	+	++	++	+
White-sided dolphin	+	++	+++	+++
Common dolphin	+++	++	+	+++
Striped dolphin		+	++	++
Spotted dolphin			+	+
Harbour porpoise	+	+++		

10.1.1 North Atlantic Right Whale

Distribution, Habitat, Abundance, and Predator and Prey

North Atlantic right whales, *Eubalaena glacialis*, herein referred to as right whales, are distributed from coastal waters of the southeastern U.S. to Newfoundland and the Gulf of

St. Lawrence (Figure 97). Most adult females give birth in coastal waters of the southeastern U.S. during the winter months. Males and non-calving females are rarely seen in that area and their whereabouts during the winter remain largely unknown. Over-wintering aggregations, however, are known to occur in Cape Cod Bay and the central Gulf of Maine. There is a northward migration in the late winter and early spring from the calving ground, with some mother calf pairs moving along the shore. In the spring, aggregations of right whales are observed feeding and socializing in the Great South Channel, Cape Cod Bay, and Massachusetts Bay. By July, right whales can be found in the critical habitats of Grand Manan Basin in the lower Bay of Fundy and Roseway Basin on the southwestern Scotian Shelf. From October onward, a steady southward, return migration occurs, with at least part of the population passing through the Gulf of Maine.

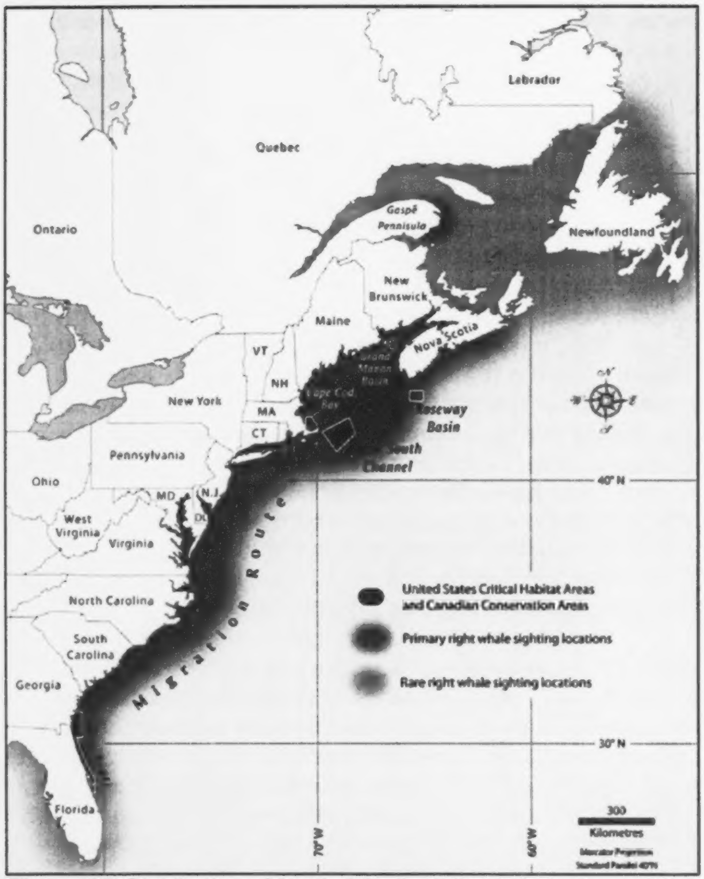

Labrador
Quebec
Ontario
Gaspé Peninsula
Newfoundland
New Brunswick
Maine
Nova Scotia
VT
NH
MA
CT
New York
Pennsylvania
Ohio
MD
N.J.
DE
West Virginia
Virginia
North Carolina
South Carolina
Georgia
Florida
Grand Manan Basin
Cape Cod Bay
Roseway Basin
Great South Channel
Migration Route
United States Critical Habitat Areas and Canadian Conservation Areas
Primary right whale sighting locations
Rare right whale sighting locations
40° N
30° N
70° W
60° W
300
Kilometres
Mercator Projection
Standard Parallel 40°N

Figure 97. *Distribution of North Atlantic right whale in the western Atlantic. The figure has been redrawn from the 'Recovery Strategy for the North Atlantic Right Whale (Eubalaena glacialis) in Atlantic Canadian Waters' (original figure prepared by K. Lagueux, New England Aquarium).*

Right whales migrate into Canadian waters to feed. Right whales in the western North Atlantic feed on a variety of organisms, but feed preferentially (and are likely dependent) on the larger, oil-rich developmental stages of the copepod *Calanus finmarchicus* (e.g. Mayo and Marx, 1990; Baumgartner et al., 2003). Species distribution likely reflects areas of high copepod populations. Other small zooplankton, such as *Pseudocalanus minutus*, *Centropages* spp., and barnacle larvae, are also occasionally eaten.

The population of right whales in the western North Atlantic was estimated to number about 322 animals (COSEWIC, 2003b). The COSEWIC (2003b) report did not present the methods used to estimate population size, however, the estimate represents the number of catalogued right whales thought to be alive in 2003. In terms of trends, the population appeared to have been declining in the 1990s (Fujiwara and Caswell, 2001), but only data through 1998 were used in those analyses. From 2002 onward, the population has exhibited relatively high calf production. By mid-decade the best estimate was approximately 350 animals (Kraus and Rolland, 2007). At present, population abundance is estimated at around 450 individuals (best estimate of 458 animals in 2009; pers comm. Right Whale Consortium).

Population Structure Relative to Moratorium Area

Right whales use Georges Bank mainly to transit from wintering areas further south to feeding areas in Canadian waters, but they also have been observed feeding on and around the Bank. In the spring, the Great South Channel (which is considered critical habitat) and the northern edge of Georges Bank are important feeding areas. During recent years, aggregations of right whales occasionally have been observed on the northern edge of the Bank into the summer months.

Life History, Location, and Timing

Female right whales give birth to a single calf in coastal waters of the southeastern U.S. between Brunswick, Georgia, and Cape Canaveral, Florida, during the winter months (Kraus et al., 1986). In 1992, the mean interval between births was 3.67 years (Knowlton et al., 1994), with a range of 2-7 years. The mean age at sexual maturity of females is not known, but the mean age when they give birth to their first calf is currently about 10 years (COSEWIC, 2003b). Right whales are found along Georges Bank in the spring, summer, and autumn months during their seasonal migration along the eastern coast of North America (with a peak during summer). They have been observed feeding along the northern edge of the Bank during summer.

Known Vulnerabilities

Significant threats to this species are activities that injure or cause fatalities. All known-human induced mortality to right whales is due to entanglements in fishing gear or vessel strikes. Potential threats to right whales and to their critical habitat associated with oil and gas exploration and extraction have been identified, however, it is not possible to evaluate these threats at this time. The potential threats include noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on right whales include displacement, habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality.

The potential effects of vessel disturbance have not been evaluated, however, vessel activity may affect the behaviour of right whales (e.g. disturb feeding or nursing) or displace whales from rich food patches. Contaminants may affect the survival or reproductive success of right whales, although no such cases have been documented to date. The potential effects of environmental change are uncertain. Threats to critical habitat would likely have to degrade prey productivity and quality, alter the oceanographic and bathymetric features that lead to prey aggregation, or exclude whales from an area of critical habitat (Brown et al., 2009).

Status Designation

Right whale was listed as 'endangered' in 2005 pursuant to SARA. Right whales were considered a single species and designated 'endangered' by COSEWIC in 1980. Its status was re-examined and determined to be 'endangered' in April 1985 and again in April 1990. In May 2003, the species was split into two (the North Atlantic and North Pacific *Eubalaena japonica* right whales) to allow a separate designation of the North Atlantic right whale. The North Atlantic right whale was designated 'endangered' by COSEWIC in May 2003.

10.1.2 Fin Whale

Distribution, Habitat, Abundance, and Predator and Prey

Fin whales, *Balaenoptera physalus*, have a global distribution and are often found in deep, offshore waters of all major oceans; primarily in temperate to polar latitudes and less commonly at ice edges and equatorial areas. Fin whales are associated with low surface temperatures and oceanic fronts during summer months. In the western North Atlantic, they are found from close inshore to well beyond the shelf break. They generally make seasonal migrations from tropical wintering areas to temperate summer feeding grounds and, as a result, the density of individuals in an area changes seasonally.

The fin whale is a filter-feeder, feeding on small schooling fish such as herring and capelin, squid, and crustaceans, including mysids and krill, though this varies geographically and seasonally. The current abundance and level of depletion compared with pre-whaling numbers are uncertain. Pre-commercial whaling estimates for the North Atlantic population are in the order of 30,000-50,000 individauls. The best available recent estimates for parts of the western North Atlantic, however, are 2269 individuals (Coefficient of Variance, CV=0.37) between Georges Bank and the mouth of the Gulf of St. Lawrence in 2006 (Waring et al., 2009). It remains unknown whether this population is stable, increasing, or decreasing.

Population Structure Relative to Moratorium Area

Fin whales are present on Georges Bank throughout the year, as the species undergo seasonal migrations in the western north Atlantic. Fin whales have been sighted in Canadian waters year-round on Georges Bank. They are found from inshore areas to the offshore, beyond the edge of the continental shelf. Fin whales are associated with oceanic fronts known for high biological productivity and low water temperatures in summer months, when they concentrate in the Gulf of St. Lawrence, on the Scotian Shelf, in the Bay of Fundy, off Newfoundland, and off Labrador.

Life History, Location, and Timing

Fin whales reach physical maturity and sexual maturity at 5-15 years for both sexes, with the average reported as 6-7 years for males and 7-8 years for females. Little information is available on where they spend their winter months or the location of calving and breeding areas. Mating is believed to occur in temperate, low-latitude areas during the winter, followed by an 11-12 month gestation period. A calf weans from its mother at 6 or 7 months of age and then follows the mother to the winter feeding ground (COSEWIC, 2005b). Females reproduce every 2-3 years, with as many as 6 fetuses being reported, although single births are far more common.

Known Vulnerabilities

The whales face a number of current threats, but none are believed to seriously threaten the population (COSEWIC, 2005b). Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on fin whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity may affect the whales behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches (COSEWIC, 2005b).

Status Designation

Fin whale is listed as a species of 'special concern' pursuant to SARA. Fin whales were considered a single species and designated as 'special concern' by COSEWIC in April 1987. In May 2005, the species was split into two populations (Atlantic and Pacific) and the Atlantic population was designated as 'special concern' by COSEWIC.

10.1.3 Sei Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sei whales, *Balaenoptera borealis*, are distributed throughout all of the world's oceans. In Atlantic Canadian waters, sei whales range from Georges Bank in the south to Labrador in the north. During the summer and early autumn months, a major portion of the northwest Atlantic sei whale population may be found on the Scotian Shelf (Mitchell and Chapman, 1977). The southern portion of their range during spring and summer includes the Gulf of Maine and Georges Bank, with sightings concentrated along the eastern margin of Georges Bank and along the southwestern edge of Georges (Waring et al., 2007).

Sei whales use primarily pelagic habitats and are most often found in deeper waters, up to the 2000 m depth contour. They appear to be associated with the continental shelf edge in the northwest Atlantic (Waring et al., 2009). Little is known about the location of breeding. This baleen whale feeds mainly on copepods and other zooplankton floating in the upper layers in the water column. Current population abudance in the northwest Atlantic is unknown. Waring et al. (2009) provided an estimate of 386 individuals (CV=0.85) for the Nova Scotia stock, based on an August 2004 line-transect sighting survey.

Population Structure Relative to Moratorium Area

Mitchell and Chapman (1977) suggested that the sei whales in this area could be separated into a Nova Scotia stock and a Labrador Sea stock. The range of the Nova Scotia stock includes the continental shelf waters of the northeastern U.S. and extends northeastward to south of Newfoundland. There is less evidence to support existence of a Labrador stock. Sei whales are present on Georges Bank throughout the year, although they are concentrated in the area during the spring and early summer.

Life History, Location, and Timing

Sei whales reach sexual maturity between 5-15 years of age and have an estimated lifespan of 50-70 years. Females breed every 2-3 years and have a gestation period of 10- 12 months. Conception and calving occurs in winter in lower latitudes. Calves are weaned on the feeding grounds after a lactation period of approximately 6 months.

Known Vulnerabilities

Threats to the sei whale population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on sei whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Sei whales in the northwest Atlantic are not listed pursuant to SARA (the Pacific population is listed as endangered). In May 2003, COSEWIC designated the Atlantic population as 'data deficient'.

10.1.4 Minke Whale

Distribution, Habitat, Abundance, and Predator and Prey

Minke whales, *Balaenoptera acutorostrata*, are found in all of the world's oceans. Whales sighted along the eastern coast of Canada and the U.S. are considered to be members of the Canadian East Coast stock, which inhabits the area from the eastern half of the Davis Strait in the north to the Gulf of Mexico. The relationship between the Canadian East Coast stock and the other three stocks in the Atlantic is uncertain (i.e. West Greenland, central North Atlantic, and northeast North Atlantic). It is also uncertain if there are separate subpopulations in the Canadian East Coast stock. During the spring and summer minke whales can be found throughout their range in the northwest Atlantic. Sightings are less common in Canadian waters during the late autumn and winter (Waring et al., 2009).

Minke whales generally occur along the continental shelf. Minke whales opportunistically feed on crustaceans (e.g. krill), plankton (e.g. copepods), and small schooling fish such as dogfish, capelin, cod, eels, herring, mackerel, salmon, sand lance, and wolfish (Waring et al., 2007). The current population abundance of minke whales is unknown. Waring et al. (2009) provided a best population estimate of 3312 whales in 2006 (CV=0.74), for an area ranging from Georges Bank to the mouth of the Gulf of St. Lawrence.

Population Structure Relative to Moratorium Area

Minke whales are usually present on Georges Bank during the spring, although some can be observed during the summer.

Life History, Location, and Timing

The estimated lifespan of minke whales is 50 years. Minke whales reach maturity at approximately six years of age for males and seven for females. Breeding is thought to occur during the winter and calving occurs during early winter. After a gestation period of 10-11 months, females give birth to a single calf. Calving locations and over-wintering habitat has not been described, although they are likely located in tropical or sub-tropical waters (Waring et al., 2007).

Known Vulnerabilities

Minke whales face the same threats as other large whales, although none are believed to seriously threaten the population (Waring et al., 2009). Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on minke whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Minke whale in the northwest Atlantic are not listed pursuant to SARA. In April 2006, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.5 Humpback Whale

Distribution, Habitat, Abundance, and Predator and Prey

Humpback whales, *Megaptera novaeangliae*, are distributed throughout the world's oceans. In the western Atlantic, they are found from the West Indies to Greenland. In eastern Canada, humpback whales are common in the summer and are typically sighted from the Gulf of Maine to southeastern Labrador. Humpback whales form relatively discrete subpopulations that exhibit distinct seasonal patterns. Humpback whales in the Gulf of Maine constitute a separate feeding stock due to the strong fidelity to the region (Waring et al., 2009). Most sightings occur in relatively coastal waters. In general, during the autumn, humpbacks migrate southward to winter and breed in tropical waters. During the spring they return to northern feeding grounds for the summer.

Humpback whales are seasonal feeders and carnivores that filter feed tiny crustaceans (e.g. krill, mainly *Euphausia superba*, copepods, etc.), plankton, and small fish (including herring, mackerel, capelin, and sandeel) from the water. The Gulf of Maine humpback whale stock appears to be increasing in abundance and a best population estimate for the subpopulation is 847 whales (CV=0.41) (Waring et al., 2009). Population estimates for the remainder of eastern Canadian waters are problematic due to uneven sampling.

Population Structure Relative to Moratorium Area

Humpback whales undergo extensive seasonal migrations and, as such, can be found on Georges Bank for much of the year, although they are absent, for the most part, during the winter (Waring et al., 2009). Humpback whales have a number of quite distinct feeding aggregations. One aggregation occurs in the Georges Bank and Gulf of Maine region, with a population size of several hundred individuals.

Life History, Location, and Timing

Humpback whales reach sexual maturity at about nine years of age. A female gives birth to one calf between January and April. The gestation period is approximately one year. Normally, females give birth every two years.

Known Vulnerabilities

Humpback whales face the same threats as other large whales but none are believed to seriously threaten the population. Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on humpback whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Humpback whale in the northwest Atlantic is listed as 'special concern' pursuant to SARA (Pacific humpbacks are listed as threatened). In May 2003, COSEWIC designated the Atlantic population as 'not at risk'.

10.1.6 Sperm Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sperm whales, *Physeter macrocephalus,* are found throughout the world's oceans in deep waters, over 1000 m deep, between about 60° N and 60° S latitudes. They may also be seen closer to shore in areas where the contintential shelf is small and water depths increase to 310-920 m (Shirihai and Jarrett, 2006). Their distribution is dependent on their food source and suitable conditions for breeding, which varies with the sex and age composition of the group. Sperm whales off eastern Canada and U.S. are thought to belong to a single north Atlantic population.

Female sperm whales are typically found in deep waters of low latitudes where sea surface temperatures are greater than 15 °C. Immature males will stay with female sperm whales in tropical and subtropical waters until they begin to slowly migrate towards the poles, anywhere between ages 4-21 years of age. Older, larger males are generally found near the edge of pack ice in both hemispheres. On occasion, however, these males will return to the warm water breeding area (Waring et al., 2007).

This toothed whale is generally a deep-water species with a diet mainly consisting of mesopelagic and benthic squids, but fishes also form part of their diet. Available data are insufficient to determine the population trend for this species. Waring et al. (2007) indicated that the best estimate of abundance for sperm whales in the northwest Atlantic is 4804 whales (CV=0.38).

Population Structure Relative to Moratorium Area

Typically males are found on Georges Bank year round near the continental slope, as females and young are usually found at latitudes less than about 40 °N. In winter, sperm whales are concentrated east and northeast of Cape Hatteras. In spring, the center of distribution shifts northward to east of Delaware and Virginia, with it being widespread throughout the central portion of the Mid-Atlantic Bight and the southern portion of Georges Bank. In summer, the distribution is similar but also includes the areas east and north of Georges Bank and into the Northeast Channel region, as well as the continental shelf south of New England. In the fall, sperm whale occurrence south of New England on the continental shelf is at its highest levels and there remains a continental shelf edge occurrence in the Mid-Atlantic Bight (Waring et al., 2007).

Life History, Location, and Timing

In the northwest Atlantic, the gestation period for sperm whales is about 14-17 months, births occur mainly in July to November, and the calving interval is 4-6 years. The mean age at sexual maturity is 19 years for males and nine years for females.

Known Vulnerabilities

Sperm whales face the same threats as other large whales but none are believed to seriously threaten the population. Threats to their population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on sperm whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Because of their deep-diving behaviour, sperm whales may be more suspectible to noise (Houser et al., 2001). Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Sperm whales in the northwest Atlantic are not listed pursuant to SARA. In April 1996, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.7 Pilot Whale

Distribution, Habitat, Abundance, and Predator and Prey

There are two species of pilot whales in the western Atlantic: the Atlantic or long-finned pilot whale, *Globicephala melas*, and the short-finned pilot whale, *G. macrorhynchus*. In late spring, pilot whales generally move from U.S. waters onto Georges Bank and into more northerly Canadian waters. They remain in these areas through late autumn. Longfin pilot whales are more common in Canadian waters. Pilot whales feed primarily on squid. Waring et al. (2007) provided a best estimate of abundance for *Globicephala* sp. of 31,139 animals (CV=0.27), derived from surveys undertaken in 2004.

Population Structure Relative to Moratorium Area

Pilot whales can be found on Georges Bank throughout the year, although they are most prevalent during the spring and summer.

Life History, Location, and Timing

For pilot whales in Canadian waters, the gestation period is approximately one year, births occur mainly from June to November, and the calving interval is around three years. The mean age at sexual maturity is 12 years for males and six years for females.

Known Vulnerabilities

Threats to pilot whales include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on pilot whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Pilot whales in the northwest Atlantic are not listed pursuant to SARA. In April 1994, COSEWIC designated the Atlantic population as 'not at risk'.

10.1.8 Bottlenose Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

Bottlenose dolphins, *Tursiops truncates*, are distributed from the tropics to southern Canadian waters. The bottlenose dolphin is rare in Canadian waters, where it is at the northern limits of its range. Two forms of the species are recognized: coastal and offshore. The offshore species is distributed primarily along the outer continental shelf and continental slope in the northwest Atlantic.

Bottlenose dolphins are generalists and feed on a variety of prey items endemic to their habitat. The species has a broad diet consisting of fish, squids and invertebrates. Coastal animals prey on benthic invertebrates and fish. Offshore animals feed on pelagic squid and fish. There are no estimates of bottlenose dolphins for Canadian waters, although NOAA Fisheries has estimated abundance in the northern migratory component of the Atlantic coastal form to be 17,466 animals (Waring et al., 2007). This popuation unit may extend into Canadian waters.

Population Structure Relative to Moratorium Area

Bottlenose dolphins are found on Georges Bank throughout the year and have a higher prevalence in spring and summer (Waring et al., 2007).

Life History, Location, and Timing

Calving of bottlenose dolphins is suggested to occur primarily from early spring to early autumn, estimates of gestation period range from 11-14 months, calves are weaned at an average age of 18-20 months, and the intercalf interval is estimated to be from 1.3-2 years. Age at sexual maturity averages 11 years for males (ranging from 9-20 years) and 12 years for females (ranging from 3.5-14 years).

Known Vulnerabilities

Threats to bottlenose dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on bottlenose dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Bottlenose dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1993, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.9 Atlantic white-sided Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

White-sided dolphins, *Lagenorhynchus acutus*, are distributed throughout the continental shelf and slope areas of temperate and sub-polar waters of the North Atlantic. The species inhabits waters from central West Greenland to North Carolina. This species exhibits seasonal movements, moving closer inshore and north in the summer and offshore and south in the winter.

The Atlantic white-sided dolphin feed primarily on fish (such as sand lance, herring, and silver hake) and squid. No estimate of the population trend for white-sided dolphins exists. The best available current abundance estimates for white-sided dolphins in the western North Atlatnic is 63,368 (CV=0.27) for the area from Georges Bank to the mouth of Gulf of St. Lawrence (Waring et al., 2009).

Population Structure Relative to Moratorium Area

Available data concerning distribution suggest the possible existence of three stocks units: Gulf of Maine, Gulf of St. Lawrence, and Labrador Sea stocks (Palka et al., 1997). White-sided dolphins are highly prevalent on and around Georges Bank for most of the year, with a decline over the winter as the species moves farther south.

Life History, Location, and Timing

White-sided dolphins have a lifespan of approximately 25 years. The mean age at sexual maturity is 8-9 years for males and 6-8 years for females. For white-sided dolphins in Canadian waters, the gestation period is about 10-12 months, births occur from May to early August, mainly in June and July, and the calving interval is 2-3 years.

Known Vulnerabilities

Threats to Atlantic white-sided dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on Atlantic white-sided dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Atlantic white-sided dolphin in the northwest Atlantic is not listed pursuant to SARA. In April 1991, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.10 Common Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

The common dolphin, *Delphinus delphis,* may be one of the most widely distributed species of cetaceans, as it is found world-wide in temperate, tropical, and subtropical seas. Their distributions vary based on interannual changes, oceanographic conditions, and seasons. They can occur on the continental shelf or farther offshore. In the northwest Atlantic, they are more common north of Cape Hatteras, North Carolina. During summer through autumn, large aggregations can be found near Georges Bank, Newfoundland, and the Scotian Shelf.

Common dolphins prefer warm tropical to cool temperate waters (10-28 °C) that are primarily oceanic and offshore, but still along the continental slope in waters 200-2000 m deep. In the western North Atlantic, they are often associated with the Gulf Stream Current. Short-beaked common dolphins also prefer waters altered by underwater geologic features where upwelling occurs. The diet of the common dolphin consists of epipelagic schooling fish and cephalopods (e.g. squid). No estimate of trend in abundance exists for common dolphins. The most recent estimate of abundance is derived from surveys by the NEFSC in 2004. Abundance was estimated as 90,547 for the area ranging from Maryland to the Bay of Fundy and 120,743 for Florida to the Bay of Fundy (Waring et al., 2007).

Population Structure Relative to Moratorium Area

Common dolphins are highly prevalent on Georges Bank during the winter season. They range from Cape Hatteras to Georges Bank during mid-January to May and move onto Georges Bank and the Scotian Shelf from mid-summer to autumn. Large aggregations have been reported on the bank in autumn. Migration onto the Scotian Shelf and continental shelf off Newfoundland occurs during summer and autumn when water temperatures exceed 11 °C (Waring et al., 2007).

Life History, Location, and Timing

Male common dolphins become sexually mature between 3-12 years and females between 2-7 years. Breeding usually takes place between the months of June and September, followed by a 10-11 month gestation period. Females give birth to a single calf and have an estimated calving interval of 1-3 years. Calving can occur annually and lactation lasts approximately 4 months. They have an estimated lifespan of up to 35 years.

Known Vulnerabilities

Threats to common dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on common dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Common dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1991, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.11 Striped Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

The striped dolphin, *Stenella coeruleoalba*, is distributed worldwide in warm-temperate to tropical waters that are oceanic and deep. In the western North Atlantic, striped dolphins are distributed along the continental shelf edge from Cape Hatteras to the southern margin of Georges Bank and also occur offshore over the continental slope and rise in the Mid-Atlantic region. In general, striped dolphins appear to prefer continental slope waters offshore to the Gulf Stream. These dolphins are often linked to upwelling areas and convergence zones.

Striped dolphins feed on a diverse diet consisting of various species of relatively small, closely-packed, midwater, 'benthopelagic' and/or 'pelagic' shoaling/schooling fish (e.g. 'myctophids' and cod) and cephalopods (e.g. squid and octopus) throughout the water column. No estimate of trend in abundance exists for striped dolphins. The most recent estimate of abundance is derived from surveys by NEFSC in 2004. Abundance was estimated as 50,055 (CV=0.57) for the area ranging from Maryland to the Bay of Fundy, and 94,462 (CV=0.40) for Florida to the Bay of Fundy (Waring et al., 2007).

Population Structure Relative to Moratorium Area

Little information exists concerning population structure in the western North Atlantic. The striped dolphin is mostly found on Georges Bank during the summer and fall.

Life History, Location, and Timing

Striped dolphins become sexually mature between the ages of 5-13 years for females and 7-15 years for males. Their mating system is generally unknown but thought to be polygynous. They give birth to a single calf during the summer or autumn after a gestation period of about one year. The interval between giving birth to calves is usually 3-4 years and lactation lasts 12-18 months. The estimated lifespan of these dolphins is up to 58 years.

Known Vulnerabilities

Threats to striped dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on striped dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Striped dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1993, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

10.1.12 Harbour Porpoise

Distribution, Habitat, Abundance, and Predator and Prey

Northwest Atlantic harbour porpoises, *Phocoena phocoena*, are widely distributed over the continental shelves of the northern hemisphere, generally within 250 kilometres of shore. The species is well adapted to cold water and is seldom found in water warmer than 16 °C. They are often sighted very close to shore in harbours and bays, particularly in the summer. In Canada, harbour porpoise range from the Bay of Fundy to northern Labrador, with three distinct populations in Newfoundland and Labrador, the Gulf of St. Lawrence, and the Bay of Fundy/Gulf of Maine. These populations regularly travel down to American waters and back to Canada (COSEWIC, 2006d). Harbour porpoise feeds mainly on small fishes such as herring, but a variety of other fishes (cod, capelin and sand lance) are also found in its diet.

There are no range-wide estimates of the abundance of harbour porpoises in eastern Canada and, in fact, much of the range of the species has never been surveyed. Surveys have been conducted in the Gulf of St. Lawrence and the Bay of Fundy-Gulf of Maine and in 2007 in Newfoundland or Labrador. Surveys in the Gulf of St. Lawrence during the summers of 1995 and 1996 provided estimates of 12,100 and 21,720 porpoises, respectively, while the most recent estimate (August 1999) of subpopulation size in the Bay of Fundy and Gulf of Maine was 89,700 (COSEWIC, 2006d). An uncorrected estimate of 1195 porpoises was derived following a survey that included waters of Newfoundland and Labrador (Lawson and Gosselin, 2009), but this estimate is lower than the approximately 7000 (uncorrected) estimated from a previous smaller-scale survey conducted around Newfoundland in 2002-2003 (pers comm. J. Lawson, DFO).

Population Structure Relative to Moratorium Area

The harbour porpoise undergoes a spring migration through the Georges Bank area to reach coastal summer feeding grounds. The population of porpoises in the Bay of Fundy and Gulf of Maine is transboundary in nature, moving frequently between Canadian and U.S. waters.

Life History, Location, and Timing

Reproduction in all harbour porpoise populations is seasonal, with ovulation and conception limited to a few weeks in early summer. Gestation lasts for 10-11 months followed by a lactation period of at least 8 months. Most mature female porpoises become pregnant each year. In the Bay of Fundy, mean age at sexual maturation for male and female porpoises was estimated to be 2.6 and 3.44 years, respectively. The harbour porpoise lifespan is approximately 24 years (COSEWIC, 2006d).

Known Vulnerabilities

The most significant threat to harbour porpoise may be entanglement in fishing gear, especially groundfish gillnets. Other threats that have been identified include habitat degradation, loss of habitat due to acoustic harassment devices used by commercial fish-farmers, and environmental contaminants.

Status Designation

At the time SARA was passed, Harbour Porpoise was listed as 'threatened' under Schedule II of SARA. It is currently being considered for listing as 'special concern' on Schedule I of SARA. Harbour porpoise was designated as 'threatened' by COSEWIC in April 1990. Its status was re-examined and confirmed in April 1991. It was then downlisted to 'special concern' in May 2003.

10.1.13 Blue Whale

Distribution, Habitat, Abundance, and Predator and Prey

Blue whales, *Balaenoptera musculus,* are found in all the oceans of the world and inhabit both coastal waters and the open ocean. Individuals belonging to the Atlantic population are observed in the St. Lawrence estuary and shallow coastal zones where the mixing of waters ensures high productivity of krill (the main food source). Three subspecies are recognized, with the Northern Hemisphere subspecies frequenting Canadian waters. Two geographically separated populations exist in Canadian waters: one in the North Atlantic and the other in the North Pacific

Blue whales are known to feed almost exclusively on euphausiids worldwide. In the North Atlantic, *Thysanoessa inermis*, *Thysanoessa raschii*, *T. longicaudata*, and *Meganyctiphanes norvegica* have been recognized as the principal blue whale prey. Blue whales feed along productive cold water upwellings in temperate to polar waters from spring to early winter. They have been described as fasting after leaving the feeding grounds (COSEWIC, 2002). Blue whale feeding aggregations are often found at the continental shelf edge where upwelling produces concentrations of krill.

Global blue whale population estimates are thought to range from 5000-12,000 individuals, although a reliable recent global population estimate does not exist. Likewise, there are no population estimates for the Atlantic population, although it is unlikely that the number of mature animals exceeds 250 individuals (Beauchamp et al., 2009). Between 20-105 blue whales are seen annually in the Gulf of St. Lawrence in photo identification studies. From 1979 to the spring of 2007, a total of 405 blue whales have been photo-identified in the estuary and northwest of the Gulf of St. Lawrence (Beauchamp et al., 2009).

Population Structure Relative to Moratorium Area

During spring, summer, and fall the Atlantic population of blue whales occurs along the north shore of the Gulf of St. Lawrence and off eastern Nova Scotia. In summer, they also occur off the coast of Newfoundland and in the Davis Strait. While they usually migrate south for the winter, some whales may remain in the Gulf of St. Lawrence. Although they are rare in the shelf waters off the eastern U.S., there have been occasional sightings off Cape Cod. It is believed this region may represent the current southern limit of the blue whales' feeding range. Sightings on Georges Bank are not common.

Life History, Location, and Timing

Blue whales mate and calve from late fall to mid-winter in the Northern Hemisphere and give birth to a single calf every 2-3 years after a 10-11 month gestation period. The age of sexual maturity is believed to be 5-15 years (Waring et al., 2007).

Known Vulnerabilities

Historical commercial whaling of blue whales is the main factor responsible for the decline in the North Atlantic population. At least 11,000 blue whales were harvested in the North Atlantic before 1960. Approximately 1500 of these were harvested in eastern Canadian waters from 1898-1951. Today, the biggest threats for this species come from ship strikes, disturbance from seismic exploration, increasing whale watching activity, entanglement in fishing gear, and pollution. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches. They also may be vulnerable to long-term changes in climate, which could affect the abundance of their prey (zooplankton) (Beauchamp et al., 2009).

Status Designation

Blue whale was listed as 'endangered' pursuant to SARA in 2005. In April 1983, COSEWIC designated the entire Canadian population of blue whales as 'special concern'. In May 2002, blue whales were split into two populations and the Atlantic population was up-listed to 'endangered' by COSEWIC in May 2002.

10.1.14 Sowerby's Beaked Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sowerby's beaked whales, *Mesoplodon bidens,* are found only in the North Atlantic. Their distribution is poorly known, as few at-sea sightings have been confirmed. From these limited data and shore stranding locations, they are considered to be the most northern North Atlantic species of the genus *Mesoplodon* (beaked whales), ranging offshore from Cape Cod to Davis Strait in the western Atlantic and from Norway to Spain in the eastern Atlantic. In the mid-Atlantic the species ranges from Iceland to the Azores and Madeira.

This species is most often sighted in deep water, along the continental shelf edge and slope and is rarely in coastal waters. Sightings of this species in Canadian waters are considered rare (COSEWIC, 2006e). Sowerby's beaked whales are considered deep divers with a diet consisting mainly of deep-sea fishes and squid. No estimate of population size or number of mature individuals within Canadian waters exists for Sowerby's beaked whales (COSEWIC, 2006e).

Population Structure Relative to Moratorium Area

There are no known seasonal movements or migrations of this species.

Life History, Location, and Timing

Little is known about the biology of Sowerby's beaked whales. Their breeding season may be from late winter to spring. They age of sexual maturity is thought to be seven years, although the estimated lifespan of this species remains unknown (Waring et al., 2007).

Known Vulnerabilities

Potential threats include noise, vessel disturbance, ship strikes, fishing gear entanglement, and contaminants. Some potential effects of noise on Sowerby's beaked whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Incidents involving beaked whale strandings near naval exercises that used mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales. Changes in behaviour and in distribution have been observed in some whale species after seismic surveys. Sowerby's beaked whales also may be vulnerable to other sources of acoustic pollution. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches. Contaminants may affect the survival or reproductive success, although no such cases have been documented to date (COSEWIC, 2006e).

Status Designation

Sowerby's beaked whale is currently listed as special concern pursuant to SARA. In November 2006, COSEWIC designated Sowerby's beaked whale as a 'species of special concern'.

10.2 SEALS

Two species of seals (i.e. grey seals and harbour seals) are known to frequent the Georges Bank moratorium area. These are described in more detail below. Two other seal species (i.e. hooded and harp seals) are considered to be infrequent visitors of the area and are not described.

10.2.1 Grey Seals

Distribution, Habitat, Abundance, and Predator and Prey

Grey seals, *Halichoerus grypus*, are found on both sides of the North Atlantic, with three major populations: Baltic Sea, northwestern Europe and eastern Canada. The North western Atlantic population, which ranges from the Gulf of Maine to southern Labrador (Figure 98), forms a single genetic population, but are divided into three components for management purposes based on the location of main breeding concentrations (Sable Island, Gulf of St. Lawrence and Eastern Shore). The western North Atlantic stock has a cold temperate to sub-Arctic distribution over the continental shelf and coastal waters, preferring areas with water depths less than 200 m. On land, they inhabit rocky coasts and islands, sandbars, and ice shelves and icebergs (Waring et al., 2007; DFO, 2008e).

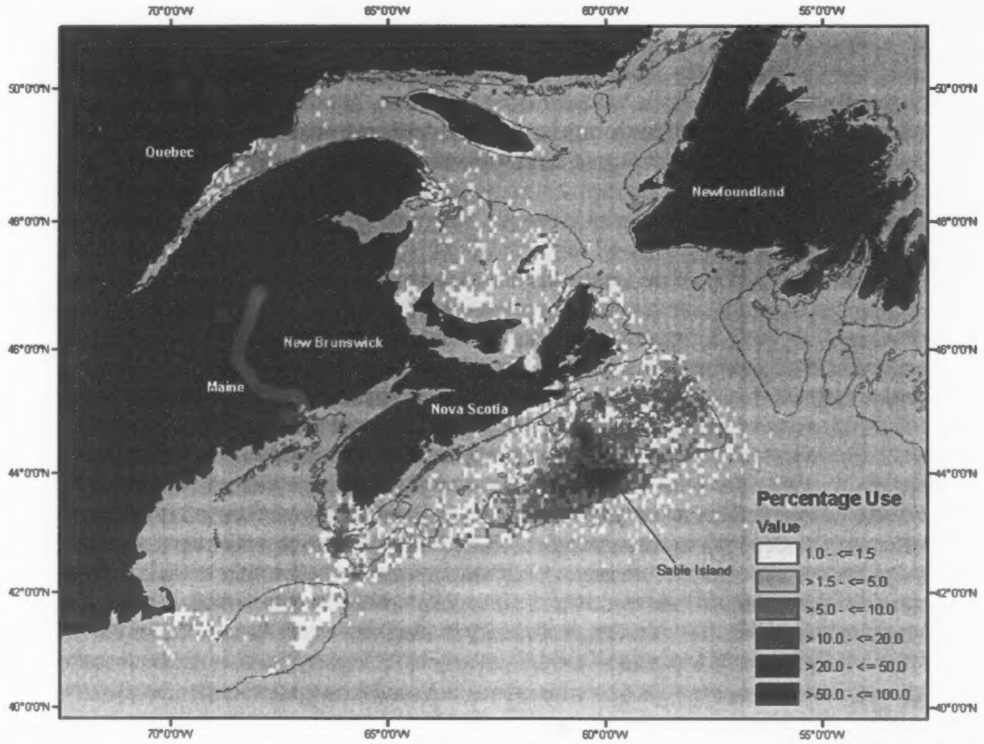

70°0'0"W
65°0'0"W
60°0'0"W
55°0'0"W
50°0'0"N
48°0'0"N
46°0'0"N
44°0'0"N
42°0'0"N
40°0'0"N
Quebec
Newfoundland
New Brunswick
Maine
Nova Scotia
Sable Island
Percentage Use
Value
1.0 - <= 1.5
>1.5 - <= 5.0
>5.0 - <= 10.0
>10.0 - <= 20.0
>20.0 - <= 50.0
>50.0 - <= 100.0

Figure 98. *Annual distribution of adult grey seals, based on locations of 70 animals fitted with Argos satellite tags on Sable Island, demonstrates limited use by the species in the Great Southern Channel, Georges Bank, and the Northeast Channel areas of the Gulf of Maine (Zwanenburg et al., 2006).*

Grey seals are generalist predators that consume mainly fish and cephalopods, but crustaceans and sea birds are occasionally taken. Prey species include cod, herring, capelin, sand lance, redfish, haddock, pollock, mackerel, flounder, skates, squid, and crab (Bowen et al., 1993). The total estimated size of the western Atlantic grey seal population at the end of the 2007 breeding season was 304,000. This is 6% higher than the equivalent estimate for 2006 and 750% higher than the estimate for 1977. Average annual rates of population increase are estimated to be 4% in the 1980s, 9% in the 1990s, and 8% in the 2000s (Thomas et al., 2007).

The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf. Population numbers of the Sable Island colony increased exponentially at an annual rate of 13% per year until the late 1990s, however, recent survey results indicate a slowing in the rate of increase to about 7% per year through 2007 (Figure 99) and an increase in the age at first birth (DFO, 2008e).

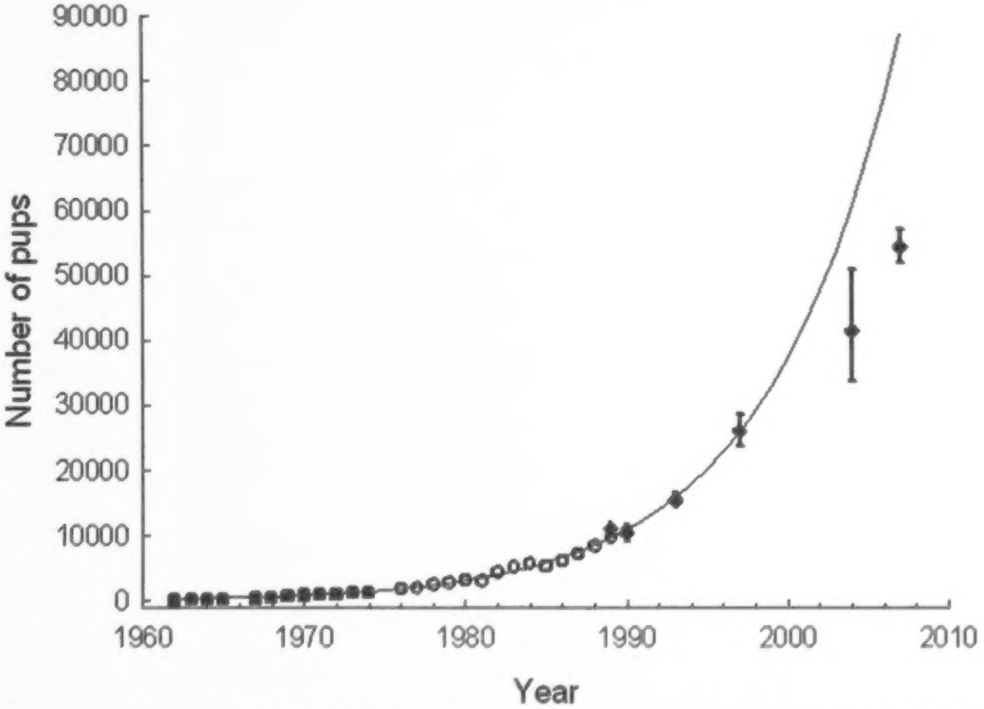


Figure 99. *Observed trends (symbols) in the number of pups and exponential model estimates (solid line) of the number of grey seal pups born at the Sable Island colony from 1962-2007 (source: Bowen et al., 2007).*

Population Structure Relative to Moratorium Area

Although wide-ranging, grey seals are non-migratory, but do show seasonal changes in distribution which are attributed to seasonal changes in prey distribution (Zwanenburg et al., 2006). Adult grey seals from Sable Island travel widely throughout eastern Canadian waters and use the area as foraging habitat (Breed et al., 2009). In addition, a small, year round breeding population is known to occur on outer Cape Cod and Nantucket Island (Waring et al., 2007).

Life History, Location, and Timing

The lifespan for male and female grey seals are 30 and 40 years, respectively. Female grey seals become sexually mature at 4-8 years and males at 4-6 years, although males may not mate successfully until greater than 8 years of age. Mating may occur on islands, isolated beaches, or on the pack ice. The breeding season varies among populations, generally taking place between January and early February. Gestations last for 9 months and pups are born at haul out sites the following year. Pups are weaned at 18 days and moult their birth coat about 4 weeks after birth. Toward the end of the nursing peroid, the adult females mates with one or more males (DFO, 2008e).

Known Vulnerabilities

Grey seals experience incidental capture in fishing gear including gillnets, trawls, seines and weirs. They are also susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion (Waring et al., 2007).

Status Designation

Grey seal is not listed pursuant to SARA. In 1999, the grey seal was designated 'not at risk' by COSEWIC.

10.2.2 Harbour Seals

Distribution, Habitat, Abundance, and Predator and Prey

Harbour seals, *Phoca vitulina*, are considered the most widely distributed pinniped. They are found in temperate, subarctic, and arctic coastal areas on both sides of the North Atlantic and North Pacific oceans. In the northwest Atlantic, they are distributed from the eastern Canadian Arctic and Greenland to southern New England and New York, and occasionally to the Carolinas. Although the stock structure of the northwestern population is unknown, harbour seals along the eastern Canadian and U.S. coasts are considered a single population (Waring et al., 2007).

Harbour seals inhabit coastal waters of the continental shelf and slope and are also commonly found in bays, rivers, estuaries, and intertidal zones. On land they inhabit rocks, sand and shingle beaches, sand bars, and mud flats (Waring et al., 2007). They are generalist feeders that consume a wide variety of fish, cephalopods, and crustaceans from surface, mid-water, and benthic habitats. Prey species include herring, mackerel, cod, whiting, and flatfish, and occasionally shrimp, crabs, mollusks, and squid (Hammill and Stenson, 2000).

In New England, the population is increasing and currently estimated to be just under 100,000 individuals. During the early 1990s, 3500 harbour seals were counted in the Bay of Fundy, however, a population estimate has not been made (Waring et al., 2007). The population on Sable Island was the largest in eastern Canada during the late 1980s, although the numbers have declined. Similarly, pup production on Sable Island declined from 600 pups in 1989 to approximately 12 pups or fewer in 2002, as a result of increased shark predation and increased land use by grey seals (Bowen et al., 2003; Waring et al., 2007).

Population Structure Relative to Moratorium Area

Harbour seals are year-round inhabitants of coastal waters of eastern Canada and Maine, and occur seasonally along the southern New England to New Jersey coasts from September to late May. Seasonal movement patterns include a general southward movement from the Bay of Fundy to southern New England in autumn and early winter followed by a northward movement from southern New England to Maine and eastern Canada prior to the pupping season (Waring et al., 2007).

Life History, Location, and Timing

The lifespan for male and female harbour seals are 25 and 35 years, respectively. Female harbour seals are sexually mature at 3-5 years and males at 4-6 years. Breeding and pupping typically occur along the coastline from Maine northwards. Unlike other seal species, mating typically takes place in water followed by a gestation peroid of 9 months. The pupping season occurs from May to early June along the Maine coast and progressively later in eastern Canada (Bowen et al., 2003; Waring et al., 2007). Moult (shedding their hair) follows the pupping and mating season. The timing and onset of moult depends on the age and sex of the animal with yearlings moulting first and adult males last (Thompson and Härkönen, 2008).

Known Vulnerabilities

Harbour seals experience incidental capture in fishing gear including gillnets, trawls, seines and weirs. They are also susceptible to boat strikes, oil spill exposure, chemical contaminants, and marine debris ingestion (Waring et al., 2007).

Status Designation

Harbour seal is not listed pursuant to SARA. In 2007, the harbour seal population was designated 'not at risk' by COSEWIC.

11.0 SEA TURTLES

Two species of sea turtle, leatherback and loggerhead, are known to occur regularly on Georges Bank. They are described in detail below. There are also records of Kemp's Ridley and Green sea turtles from the Scotian Shelf. The Canadian Sea Turtle Network has responded to several stranded Kemp's Ridley turtles, including a cold-stunned juvenile recovered in the Bay of Fundy. Both species occassionally occur on Georges Bank, albeit less frequently than leatherbacks and loggerheads, so they are not described in detail here. Select sea turtle species are summarized in the Appendix.

11.1 LEATHERBACK TURTLE

Distribution, Habitat, Abundance, and Predator and Prey

Adult and subadult leatherback turtles, *Dermochelys coriacea,* in the northwest Atlantic undergo an annual migration between breeding areas at low latitudes and foraging habitat in temperate waters (James et al., 2005a). Leatherback turtles are found in tropical and temperate waters of the Atlantic, Pacific, and Indian Oceans. Leatherbacks that forage in Canadian waters originate (nest) from beaches in South and Central America, the Caribbean, and continental U.S. (James et al., 2007). The west coast of Africa hosts one of the largest remaining nesting populations of leatherbacks in the Atlantic (Witt et al., 2009); this stock does not utilize high latitude foraging areas.

While mature leatherbacks are regularly encountered in temperate waters, records of juveniles are from tropical waters. Little is known about hatchling and juvenile habitat requirements, however, since they are never seen in temperate waters it is assumed that the leatherbacks gain cold tolerance as they mature. The annual return of leatherbacks to northern latitudes of the western Atlantic in late spring through summer (Figure 100) coincides with the seasonal availability of gelatinous zooplankton prey (James et al., 2005a,b; James et al., 2006; James et al., 2007), including the lion's mane jellyfish (*Cyanea capillata*), a preferred forage species. Leatherbacks concentrate in areas where productivity is high, along oceanic frontal systems and along vertical gradients located at oceanic fronts.

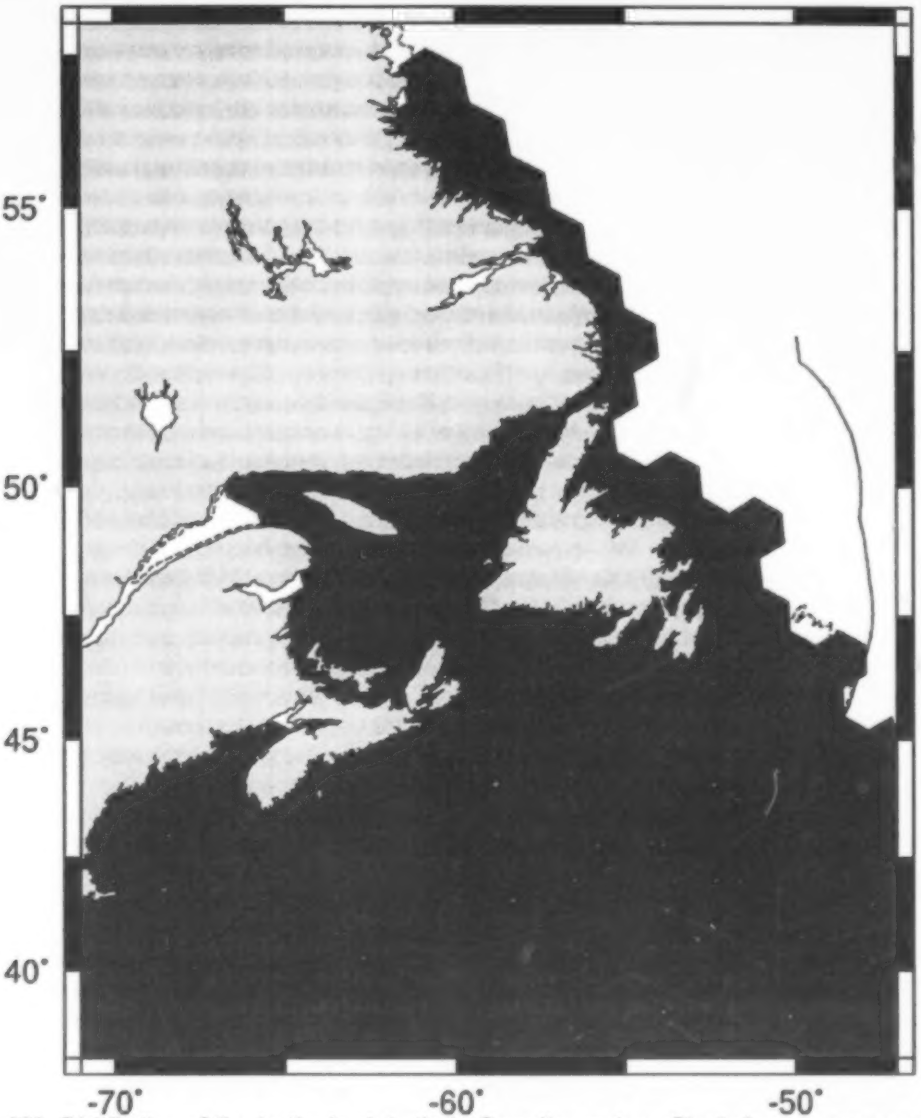


Figure 100. *Distribution of the leatherback turtle in Canadian waters. Shaded areas represent areas of known occurrence from sightings and satellite telemetry data. Dashed line represents 100m isobath. Solid line denotes Canadian 200 mile limit (Exclusive Economic Zone).*

Prey consumed by leatherbacks in temperate northwest Atlantic waters includes several species of gelatinous zooplankton (e.g. *Cyanea capillata*) (James and Herman, 2001). Trend analyses for six nesting area management units (i.e. North Caribbean, Western Caribbean, Southern Caribbean/Guianas, Florida, South Africa, and Brazil) suggests that, with the exception of the Western Caribbean, these stocks may currently be stable or increasing (TAWG, 2007). An ocean basin-wide population estimate for leatherbacks in the Atlantic is not available, as only mature female leatherbacks come ashore (to nest). Therefore, only two life history stages (nesting females and hatchling production) can be estimated directly, yielding a North Atlantic population estimate of 34,000-94,000 mature leatherbacks (TAWG, 2007).

The large range in this population estimate reflects uncertainty in nest numbers and extrapolation of these data to adults. In-water survey methods have been infrequent and largely opportunistic, focusing on only a small fraction of leatherback foraging habitat. Apart from the Cetacean and Turtle Assessment Program surveys from 1978-1982 (Shoop and Kenney, 1992), and annual aerial surveys for right whales conducted by the National Marine Fisheries Service, waters adjacent to and including portions of the Georges Bank moratorium area have not been regularly surveyed. As such, in-water abundance trends for the moratorium area are not available.

Population Structure Relative to Moratorium Area

The leatherback 'season' in Canadian waters extends from May through December, with the majority of turtles present from July through to mid-October. High use leatherback foraging areas in Atlantic Canada include waters off Cape Breton Island, parts of the south coast of Newfoundland, and southern Gulf of St. Lawrence (James et al., 2005b; James et al., 2006). The largest seasonal concentrations of leatherbacks in the temperate northwest Atlantic occur on the continental shelf and slope, although the species is also present further offshore. Leatherbacks are widely distributed in Atlantic Canada between April and December (James et al., 2005b; James et al., 2006).

Adult and large subadult leatherbacks (curved carapace length greater than 100 cm) utilize the Georges Bank moratorium area for foraging. Satellite telemetry studies have revealed that some leatherbacks migrate north to slope waters adjacent to Georges Bank (in the existing moratorium area) in late spring (e.g. James et al., 2005a), where they may remain for several weeks before moving onto the continental shelf. While leatherback distributions on the Scotian Shelf appear to generally shift from southwest to northeast as the foraging season progresses (James et al., 2006; James et al., 2007), slope waters adjacent Georges Bank and, to a lesser extent, waters within the 100 m isobath of Georges Bank, are also used by turtles from late spring through fall (James et al., 2005a).

Slope waters east and southeast of the Northeast Channel provide high use habitat for leatherbacks throughout the summer and fall foraging periods, with some animals departing this area as late as December (Sherrill-Mix et al., 2008). While the temporal window for initiation of southward migration from shelf foraging areas of the northwest Atlantic is relatively narrow, there is considerable variation in departure date among turtles present in offshore foraging areas, including waters corresponding to the Georges Bank moratorium area (Sherrill-Mix et al., 2008). Individual turtles exhibit fidelity for broad foraging zones in the temperate eastern or western Atlantic, however, their routes to and from these areas can vary between years (James et al., 2005b).

Life History, Location, and Timing

Leatherbacks depart temperate foraging areas for tropical and subtropical feeding and breeding areas in the fall. Little information regarding mating, in term of where or when it occurs, is available. The females primarily nest in the tropics on open beaches with minimal amounts of abrasive material. The female leatherback excavates a nest and lays 50-166 eggs. They lay an average of 6 clutches each season at 8-12 day intervals. The eggs hatch in approximately 60-65 days. The sex ratio of the hatchlings is determined by nest temperature during development (COSEWIC, 2001).

Known Vulnerabilities

A long lifespan, very high rates of egg and hatchling mortality, and a late age of maturity (24.5- 29 yrs) (Avens et al., 2009) make the leatherback particularly vulnerable to even small increases in rates of mortality among adults and older juveniles. Entanglement in lines associated with fixed fishing gear constitutes the principal source of human-induced injury and mortality for leatherbacks in Canadian waters (James et al., 2005a). Vessel strikes and ingestion of marine debris, particularly plastics (Mrosovsky et al., 2009), constitute additional threats to leatherbacks in the marine environment. While the leatherback's status and biology preclude direct in-situ or captive measurement of physiological and behavioural response to marine noise, some studies (O'Hara and Wilcox, 1990l; McCauley et al., 2000b) indicate that other sea turtles are able to detect sound frequencies in the range of those generated during seismic surveys.

Status Designation

The Atlantic Canada population of leatherback turtle is listed as 'endangered' pursuant to SARA.The leatherback turtle was designated as 'endangered' by COSEWIC in April 1981. Its status was re-examined and confirmed by COSEWIC in May 2001.

11.2 LOGGERHEAD TURTLE

Distribution, Habitat, Abundance, and Predator and Prey

Loggerhead turtles, *Caretta caretta,* are circumglobal, inhabiting continental shelves, bays, estuaries, and lagoons throughout the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans. In the western Atlantic, the turtle's range extends from Newfoundland to Argentina (NOAA, 2006; Conant et al., 2009). In Atlantic Canada, loggerhead turtles occur in offshore waters from Georges Bank to the Flemish Cap. Temperature is known to be influential to loggerhead distributions. They are encountered in waters greater than 15 °C, especially between 20-25 °C (Conant et al., 2009). Nesting occurs primarily in the subtropics with the majority occurring in the western rims of the Atlantic and Indian Oceans. Adult loggerheads make extensive migrations between foraging areas and nesting beaches. Little is known of the geographic origin of loggerheads that have been found in Canadian waters.

The habitat of loggerhead turtles changes throughout their life cycle. Adult females go ashore to lay eggs and seem to prefer steeply sloped, high energy beaches. Young juveniles are typically found among drifting *Sargassum* mats in warm ocean currents. Older juveniles and adults are most often found in coastal waters and tend to prefer a rocky or muddy substrate over a sandy one. They may also be found near coral reefs and venturing into salt marshes, brackish lagoons, and the mouths of rivers (Conant et al., 2009). The turtles are primarily carnivorous but also consume bottom-dwelling invertebrates, such as sponges, jellyfish, mussels, clams, oysters and shrimp. Very little is known of the diet of oceanic juveniles (MarineBIO, 2006; Conant et al., 2009).

There are currently no estimates of loggerhead turtle abundance in Atlantic Canadian waters. Only two loggerhead nesting beaches have greater than 10,000 females nesting per year: South Florida (U.S.) and Masirah Island (Oman). The status of the Oman nesting colony has not been evaluated recently. Total estimated nesting in the U.S. has fluctuated between 47,000-90,000 nests per year over the last decade. Recent analyses of nesting data from the Index Nesting Beach Survey program in southeast Florida show that the population is declining. Similarly, long-term nesting data show loggerhead nesting declines in North Carolina, South Carolina, and Georgia (Conant et al., 2009).

Population Structure Relative to Moratorium Area

Loggerhead turtle bycatch rates are highest in the summer and fall, when the species is believed to be most abundant in Atlantic Canadian waters. Based on limited bycatch data from commercial fisheries, it appears that loggerheads use the warm waters of the Gulf Stream off the Scotian Shelf, Georges Bank, and the Grand Banks as foraging habitat from July through October.

Life History, Location, and Timing

It is estimated that loggerhead turtles live approximately 30-62 years and reach sexual maturity between 14-42 years (Conant et al., 2009). Mating takes place in late March to early June and the eggs are laid throughout the summer. The female excavates a nest and lays up to 125 eggs. A female will nest every 6-21 days, or 2-8 times, during a single nesting season. The eggs incubate for approximately 2 months, depending on the temperature and hatch from April to early September (SFSC, 2009).

Known Vulnerabilities

Loggerheads face threats on both nesting beaches and in the marine environment. The greatest cause of decline and the continuing primary threat to loggerhead turtle populations worldwide is incidental capture in fishing gear. Some studies (O'Hara and Wilcox, 1990; McCauley et al., 2000b) indicate that other sea turtles are able to detect sound frequencies in the range of those generated during seismic surveys.

Status Designation

Loggerhead turtle is not listed pursuant to SARA. In April 2010, they were assessed as 'endangered' by COSEWIC.

12.0 MARINE BIRDS

Eastern Georges Bank is an extremely important area for marine birds throughout the year (Figure 101). The peak in bird activity occurs during the summer (Powers and Brown, 1987) when migrants that breed in the South Atlantic, such as the greater shearwater (*Puffinus gravis*), sooty shearwater (*P. griseus*), and Wilson's storm-petrel (*Oceanites oceanicus*), dominate the bird community. Leach's storm-petrels (*Oceanodroma leucorhoa*) are also found on the Bank in the summer when adults are foraging from nesting colonies located in coastal Nova Scotia and along the Gulf of Maine coast. In fall, the shearwaters and storm-petrels are gradually replaced by northern fulmars (*Fulmarus glacialis*), northern gannets (*Morus bassanus*), large gulls, and black-legged kittiwakes (*Rissa tridactyla*), which are migrating from breeding locations in Arctic Canada, Greenland, Newfoundland, and northern Europe.

The bird community remains similar through the winter, although gannets are moving south off the Bank and Alcids are arriving from northern breeding areas. In spring, fulmars remain abundant and gannet numbers again increase as they migrate over the Bank to their breeding colonies. During this time, there is also an influx of arctic-breeding phalaropes to Georges Bank, and shearwaters and storm-petrels arrive from the southern hemisphere. A total of 32 marine bird species from 8 families regularly are found on Georges Bank (Powers and Brown, 1987).

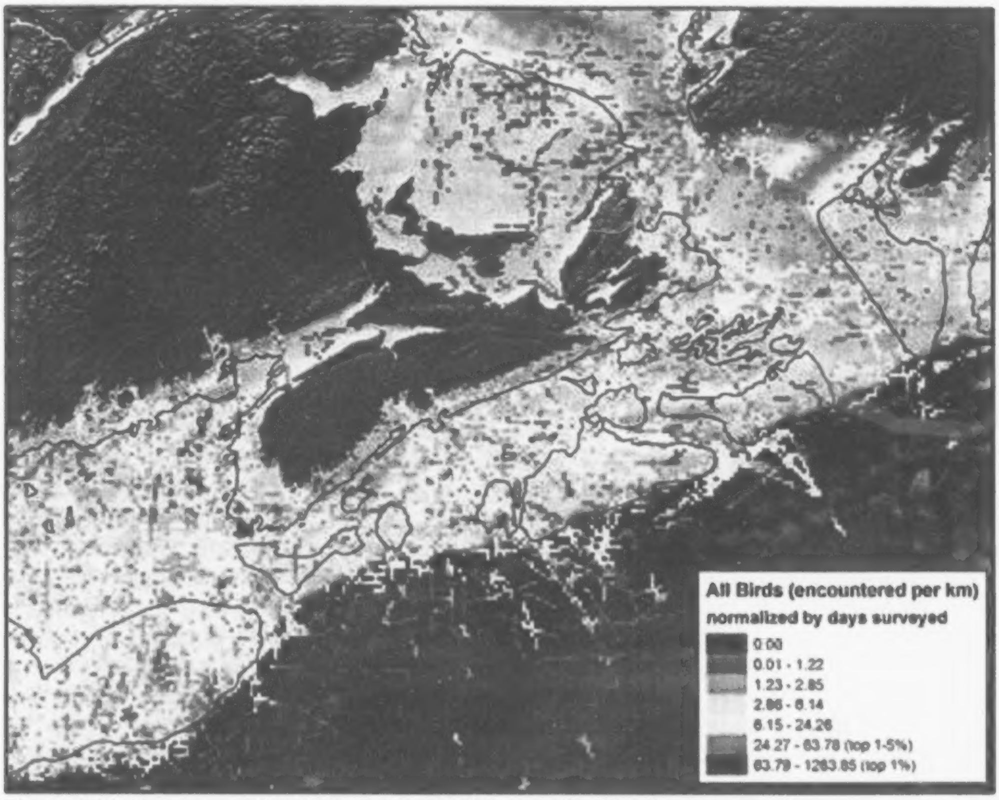


***Figure 101.** Year-round distribution of seabirds normalized by days surveyed.*

Marine birds are extremely vulnerable to the effects of oil pollution (Wiese, 2002). Feathers readily absorb oil, decreasing their ability to insulate birds from the cold and reducing the qualities of waterproofing and buoyancy. A very small amount of oil can lead to death through hypothermia and starvation. Furthermore, birds can die from ingesting petroleum products while preening their feathers. At certain times of the year and, at certain locations, marine birds may concentrate in large numbers, where oil spills could have a large impact on the global population. In addition, delayed maturity and low fecundity in seabirds make recovery from pollution events difficult. Another important threat to seabirds related to offshore oil and gas activities is the potential attraction of birds to artificial light sources on ships and at offshore installations, including light from gas flares. Birds may be killed directly when they fly into the structure or flare or indirectly when they become stranded on the platform. The effects of light attraction on birds, however, have not been well quantified.

Platforms may also act as refuges or artificial reefs, where birds congregate to take advantage of increased food resources, making them more vulnerable to accidental hydrocarbon spills where these installations are located. The Eastern Canada Seabird at Sea (ECSAS) database contains information on pelagic bird surveys from vessels traveling offshore, including data collected between 1965-1992 for the Programme Integré de Recherche sur les Oiseaux Pélagiques (PIROP) (Brown et al., 1975; Brown, 1986; Lock et al., 1994) and more recent data collected since 2005. Most of the marine bird abundance data for Georges Bank were collected by Manomet Bird Observatory between 1980 and 1988. The following are descriptions of the most common seabird species sighted on Georges Bank. The timing of the most common species on Georges Bank is highlighted in Table 4. Select marine bird species are summarized in the Appendix.

Table 4. *Seasonal occurrence of seabird species commonly observed on Georges Bank.*

	Month											
Species	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Greater Shearwater					←	─	─	─	─	─	─	→
Red Phalarope			←→							←→		
Wilson's Storm-Petrel			←	─	─	─	─	─	─	→		
Thick-billed Murre	─	─	─	→								←─
Northern Fulmar	─	─	─	─	─	─	→		←	─	─	─
Herring Gull	─	─	─	─	─	─	─	─	─	─	─	─
Great Black-backed Gull	─	─	─	─	─	─	─	─	─	─	─	─
Black-legged Kittiwake	─	─	─	→						←	─	─
Leach's Storm-Petrel			←	─	─	─	─	─	→			
Sooty Shearwater				←	─	─	─	─	→			
Dovekie	─	─	→							←	─	─
Cory's Shearwater							←	─	─	→		
Northern Gannet			←	─	→					←	─	─
Red-necked Phalarope					←	→				←	→	

12.1 GREATER SHEARWATER

Distribution, Habitat, Abundance, and Predator and Prey

Greater shearwaters, *Puffinus gravis,* breed at three main sites in the south Atlantic. These are two very remote islands in the Tristan da Cunha group and on Gough Island.

Individuals leave the breeding grounds in April and migrate along the coasts of South and North America to feeding grounds in the north Atlantic. Virtually all of the world's population is thought to spend the non-breeding season in the northwest Atlantic (Brown, 1986). Adults return south to the breeding islands in September, although younger birds likely remain in the area through November. New tagging studies show birds follow a Z-shaped migration route (Ronconi, 2007), using wind patterns to cross the Atlantic to the west coast of Africa, then south along the African coast before crossing the Atlantic a second time to coastal regions of Argentina. From there, they turn east again, returning to breeding colonies in the central south Atlantic. Greater shearwaters eat fish, squid, and crustaceans from the surface of the water, but are also known to pursue prey underwater. The species has an extremely large range, is very abundant, and the population appears stable.

Population Structure Relative to Moratorium Area

Data collected by the Manomet Bird Observatory from 1980-1988 show that the greater shearwater is the bird species most frequently observed on Georges Bank. The first sightings of this species on the Bank typically occur in May. They remain abundant until November and some observations are recorded through December (Table 4). These late observations are most likely of non-breeding or immature birds. Individuals may stay in the vicinity of the Bank for the summer, use the Bank as a stop-over site on their way to other feeding locations in northeast Atlantic, or, because these shearwaters are highly pelagic and can move great distances in a relatively short period of time, they may also move on and off the Bank throughout the season.

Life History, Location, and Timing

Individuals reach sexual maturity between 3-7 years of age. They arrive on their breeding grounds in mid-September and, by November, the female will lay a single egg in a burrow, which is incubated for about 6 weeks. Both adults are involved with the care of the egg and chick. Chicks are fed a regurgitated mixture of fish and stomach oil for approximately 6 weeks, at which time they leave the burrow to take their first flight from the colony. Adults will abandon the colony first in April, while the young will remain into May (Brown, 1986). Activity at the colony is nocturnal. Adult birds show long term fidelity to both their mate and to their nest site. Adult survivorship is high and birds may live up to 20 years.

Known Vulnerabilities

Like most marine birds, greater shearwaters are extremely vulnerable to the effects of oil pollution. In addition, shearwaters are attracted to the lights associated with vessels and offshore platforms, although the impact of this mortality source on the population is not known.

Status Designation

Greater shearwater is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.2 OTHER SHEARWATERS

Other shearwaters that have been observed on Georges Bank include the sooty shearwater (*Puffinus griseus*), Manx shearwater (*P. puffinus*), Audubon's shearwater (*P. lherminieri*), and Cory's shearwater (*Calonectris diomedea*). Like the greater shearwaters, sooty shearwaters breed on remote islands in the southern hemisphere and spend their non-breeding season in the north Atlantic. They are found in relatively high numbers on Georges Bank between April and September (Table 4). Sooty shearwaters were listed as 'near threatened' in 2004 by the IUCN due to a moderately rapid population decline from the impact of fisheries, the harvesting of its young, and possibly climate change (IUCN, 2010).

The bulk of the Manx shearwater population breeds in the United Kingdom, but a small number (approximately 100 pairs) breed on Middle Lawn Island off southern Newfoundland (Lien and Grimmer 1978). Sightings on the Bank have been recorded during the summer. Audubon's shearwaters breeding in the Caribbean have only rarely been seen on the Bank. Cory's shearwaters breed in the northeast Atlantic and are most common on the Bank in August and into the fall (Table 4). These three shearwater species are all listed as 'least concern' by IUCN. The globally-endangered (IUCN, 2010) Bermuda petrel (*Pterodroma cahow*) moves north from breeding areas in Bermuda, following warm waters on the western edges of the Gulf Stream. It has been sighted infrequently in waters adjacent to Georges Bank.

12.3 RED PHALAROPE

Distribution, Habitat, Abundance, and Predator and Prey

Red phalaropes, *Phalaropus fulicarius,* breed in the circumpolar Arctic, primarily on coastal tundra north of 60°N (Tracy et al., 2002). The species migrates over the open ocean to winter in south temperate and subtropical/tropical waters. In spring, individuals breeding in the eastern Canadian Arctic are believed to travel from west and southwest Africa across the Atlantic, over Georges Bank and the Scotian Shelf, before arriving into Canadian Arctic waters in early to mid-June (Brown, 1986). They are found mostly along ocean fronts, associated with high concentrations of zooplankton (Tracy et al., 2002). On the breeding grounds, red phalaropes are insectivorous in wetlands. At sea, marine copepods and amphipods are their main prey choice, but diet may also include fish eggs, larval fish, mysids, and euphausiids (Tracy et al., 2002). Overall, numbers across their range appear to be declining, although abundance estimates are extremely difficult to obtain. Surveys in the eastern-central Canadian Arctic indicate a dramatic decline (76%) between 1975-76 and 1994-95 (Tracy et al., 2002).

Population Structure Relative to Moratorium Area

Data show that the red phalarope was the second most abundant bird species observed on Georges Bank from 1980-1988. They typically arrive on the Bank from the Mid-Atlantic Bight in May where they remain for the month to feed before moving to their breeding grounds in the eastern Canadian Arctic (Table 4). After the breeding season, large flocks stage in the Bay of Fundy in August and September and then move either southeast across the Atlantic or south along the east coast of North America (Tracy et al., 2002). They are common on Georges Bank during October (Table 4). They appear to be less common on the Bank during their southward migration in the fall compared to their northward migration in the spring.

Life History, Location, and Timing

Red phalaropes likely begin breeding as yearlings (Tracy et al., 2002). Females typically lay four eggs in one or two clutches a season. The male incubates the eggs for about 20 days and, alone, broods the young through the first 12 days after hatching. Chicks are precocial at hatching, meaning that they hatch fully covered with down and leave the nest to find food on their own the same day of hatch. Males are associated with the young for up to 12 days and young are able to fly at about 18 days post-hatch (Tracy et al., 2002). This species is usually monogamous within a single breeding season, although females are known to mate with multiple males. No information exists on life span and survivorship.

Known Vulnerabilities

As with most other marine bird species, red phalaropes are highly susceptible to oil pollution. An oil spill coinciding temporally and spatially with concentrations of this species on Georges Bank may be expected to have a large impact on the global population.

Status Designation

Red phalarope is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.4 OTHER PHALAROPES

Red-necked phalaropes, *P. lobatus*, also occur on Georges Bank during their spring and fall migration, slightly later than red phalaropes and in smaller numbers. They migrate primarily along the coast or offshore, but also overland. Historically, the western Bay of Fundy was an important fall staging area for huge densities of red-necked phalaropes (up to 20,000 birds km^{-2}), although numbers have been declining since the mid-1980's (Rubega et al., 2000). It is not known whether this decline represents a change in population size or whether the phalaropes are staging elsewhere in response to changing ocean conditions. The red-necked phalarope has been identified by COSEWIC as a high-priority candidate for status report production. It is listed as 'least concern' by the IUCN.

12.5 WILSON'S STORM PETRELS

Distribution, Habitat, Abundance, and Predator and Prey

Like the greater and sooty shearwaters, Wilson's storm-petrels, *Oceanites oceanicus,* breed in the southern hemisphere and spends the non-breeding season in the north Atlantic. They migrate between hemispheres in all oceans, although they are uncommon in the Pacific. In the Atlantic, the main northward migration occurs over the western sector (Harrison, 1988), and birds typically arrive on Georges Bank by May (Table 4). They begin their return to southern breeding grounds in August, but are observed on the bank into October. Non-breeders may remain in the north Atlantic throughout the year (Harrison, 1988).

Wilson's storm-petrels are often observed at sea in large flocks reaching several thousands during migration. They feed by dipping their feet into the water, capturing prey from the surface. They feed primarily on amphipods, *Euphausia*, squid, and fish. They readily follow ships, attracted by the offal, and whales and dolphins. Wilson's storm-petrels are numerous (several million pairs) and wide ranging. Although very difficult to assess, there is no evidence to suggest large population changes in this species.

Population Structure Relative to Moratorium Area

Wilson's storm-petrels are observed on Georges Bank from May to October (Table 4). They are highly pelagic and may fly great distances in a relatively short period of time. Movement on and off the Bank throughout the summer is likely.

Life History, Location, and Timing

Age of first breeding is estimated to be 5 years for the Wilson's storm-petrel. They nest in cavities and in tunnels excavated by the birds under boulders. Adults usually enter and leave the nest site at night to minimize their predation risk. Just one egg is laid per nest, and both parents incubate the egg (5-6 weeks) and feed the chick (6-7 weeks). The birds return to their colonies in Antarctica in November to December and lay their egg in December to January (Brown, 1986). Fledging and dispersal from breeding colonies begins in April. Typical of many seabirds, adult survivorship is high, and birds are relatively long lived.

Known Vulnerabilities

Wilson's storm-petrels are vulnerable to oil pollution, and their attraction to lights on platforms and vessels kills an unknown number of individuals. The impact of this source of mortality on the population is not known.

Status Designation

Wilson's storm-petrel is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.6 OTHER STORM PETRELS

Leach's storm-petrels, *Oceanodroma leucorhoa,* are also relatively abundant on Georges Bank from March through September (Table 4). Unlike the Wilson's storm-petrel, this species breeds in the northern hemisphere. In the northwest Atlantic, they breed on islands from southern Labrador to Massachusetts. The largest breeding population in the world is thought to be on Baccalieu Island in Newfoundland, where some 3.5 million pairs are estimated to breed (Sklepkovych and Montevecchi, 1989). The breeding season for Leach's storm-petrels extends from late May through September. They lay a single egg in a burrow and both parents incubate the egg and raise the chick. Adults eat a variety of plankton and nektonic species, including fish, cephalopods, crustaceans, and jellyfish (Huntington et al., 1996). They concentrate at fronts and eddies, where upwelling brings prey to the surface, and may forage more than

200 km from breeding colonies (Huntington et al., 1996). Like the Wilson's storm-petrel, this species is vulnerable to oil spills and significant mortality may occur when individuals are attracted to the lights and flares associated with oil exploration and production activities. It is listed as 'least concern' by the IUCN.

12.7 THICKED-BILLED MURRE

Distribution, Habitat, Abundance, and Predator and Prey

Thick-billed murres, *Uria lomvia,* have a circumpolar arctic and boreal distribution. In Atlantic Canada, they breed in southern Labrador, as well as in small numbers on the north shore of the Gulf of St. Lawrence and in Newfoundland. The largest colonies are in the High Arctic. Murres that breed in the eastern Canadian Arctic, winter mainly in the offshore of Newfoundland and Labrador. Smaller numbers winter in the Gulf of St. Lawrence, Scotian Shelf, Bay of Fundy, and Georges Bank. They are found mainly in continental shelf waters, not commonly close inshore (Brown, 1986). Like all species in the family Alcidae, thick-billed murres pursue their prey underwater using their wings. Typical dive depth is about 20 m, but depths as great as 200 m have been recorded (Gaston and Hipfner, 2000). Adults prey mainly on midwater schooling fish such as cod, smelt, and sand lance, but also on crustacea, benthic fishes, shrimps, squid, and annelids (Gaston and Hipfner, 2000). Numbers in the eastern Canadian Arctic are believed to be stable or slightly increasing, although numbers in Greenland decreased substantially from the 1940s to the 1980s as a result of hunting (Gaston and Hipfner, 2000).

Population Structure Relative to Moratorium Area

Thick-billed murres breeding in the Canadian Arctic and western Greenland move south to Newfoundland waters, arriving anytime between October and December. Smaller numbers winter farther south off the coast of the northeastern U.S. Return migration begins as early as March. Individuals typically reach their breeding grounds by mid-May. Data show thick-billed murre sightings on Georges Bank from December through May (Table 4).

Life History, Location, and Timing

Thick-billed murres typically breed for the first time at age 4-5 years. They nest on cliff ledges and sometimes in caves or crevices (Gaston and Hipfner, 2000). One egg is laid and both the male and female take turns to incubate for about 5 weeks. Both parents also care for the young, returning to feed 2-6 times a day for about 3 weeks. Although not fully developed, the chick departs the colony at this time by jumping from the nest site into the sea. It is the male parent that leaves with the chick, feeding it on the surface of the ocean for a month or more. In the Atlantic, the breeding season begins in late May and continues through early September. Adult survivorship is 90%, and band recoveries have shown birds living in excess of 25 years (Gaston and Hipfner, 2000).

Known Vulnerabilities

Like all members of the family Alcidae, thick-billed murres are extremely vulnerable to the effects of oil pollution as they spend most of their time on the surface of the water. The species often congregates in large numbers and will dive underwater rather than fly if disturbed. High adult survival rates and low rates of fecundity mean population recovery from oil spills is difficult. Wiese (2002) estimates several tens of thousands are killed every year off the coast of Newfoundland from chronic oil pollution. Population declines over the next 20 years are likely if human-induced mortality remains at current levels (Wiese, 2002).

Status Designation

Thick-billed murre is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.8 OTHER ALCIDS

Other members of the family Alcidae observed on Georges Bank include the common murre (*U. aalga*), dovekie (*Alle alle*), Atlantic puffin (*Fratercula arctica*), and razorbill (*Alca torda*). Most of the common murres in Atlantic Canada breed in eastern Newfoundland (Brown, 1986) and are observed on Georges Bank in the winter. As common murres are difficult to tell apart from thick-billed murres during at-sea surveys, the ratio of thick-billed to common murres in our data may not be representative of the true distribution. Powers and Brown (1987) suggest common murres are more abundant on Georges Bank than thick-billed murres. Dovekies are also observed on the Bank during their non-breeding season, departing for breeding colonies in Greenland in late March, returning again in early October (Table 4). Over 12 million pairs of Atlantic puffins are estimated to breed in the North Atlantic (Brown, 1986). During the winter, they are widely dispersed and well offshore, but only occasionally observed on Georges Bank. Razorbills breed in the boreal and low Arctic regions of the North Atlantic (Brown, 1986) and have been observed in small numbers on Georges Bank and inshore from January through May. All of the alcid species are listed as 'least concern' by the IUCN.

12.9 NORTHERN FULMAR

Distribution, Habitat, Abundance, and Predator and Prey

Northern fulmars, *Fulmarus glacialis,* are related to the petrels and shearwaters and are abundant in both Alaska and the Canadian Arctic. The majority of fulmars in North America breed in the eastern Canadian Arctic above 65°N (Hatch and Nettleship, 1998). They are widely dispersed throughout the Atlantic during the non-breeding season, but major concentrations exist on the Grand Banks off Newfoundland. They are commonly found over deep, cold waters in low-Arctic regions, and show a preference for shelf break habitats (Hatch and Nettleship, 1998). Northern fulmars arrive at breeding colonies in the High Arctic in late April or early May, and typically leave by mid-October.

Northern fulmars are omnivorous, eating fish, cephalopods, zooplankton, offal, and carrion (Hatch and Nettleship, 1998). They have been observed feeding at the ice edge on macrozooplankton, and in areas of local upwelling. This species is known to associate with black-legged kittiwakes during the chick-rearing period, and also with gray whales (Hatch and Nettleship 1998). They pick their prey from the surface of the water, but may also plunge under the surface and pursue their prey. Fulmars are well known for following fishing vessels and scavenging offal. The Atlantic population of northern fulmars has expanded in both range and number over past 200 years (Hatch and Nettleship, 1998). It is believed that the modern trawl fishery may be responsible for the expansion, although oceanographic changes may also play a role. At present, the Atlantic population appears stable.

Population Structure Relative to Moratorium Area

Data show sightings of northern fulmar on Georges Bank throughout the year except during August (Table 4). They are common from January to March. Birds arriving earlier and those departing later are most likely either immature birds or non-breeders.

Life History, Location, and Timing

Northern fulmars delay breeding until perhaps as old as 5 years. In Greenland, immature birds may remain at sea for three years before visiting the breeding colony. Breeding phenology is largely tied to environmental conditions, but in the Atlantic, birds typically arrive on the colony in mid to late-April (Hatch and Nettleship, 1998). One egg is laid on a slope or cliff edge nest, both parents incubate for almost 50 days, and both parents feed the chick for another 50 days. When chicks fly from the nest they are independent of their parents. Most leave the colony by late September to scatter widely over the north Atlantic, although some may remain close to breeding colonies for much of the year (Hatch and Nettleship, 1998). Adults show strong fidelity to breeding sites. They have high annual survivorship (95%) and may live in excess of 30 years (Hatch, 1987).

Known Vulnerabilities

As with most other marine bird species, northern fulmars are highly susceptible to oil pollution. The propensity of fulmars to concentrate in large numbers makes them vulnerable to pollution events, including oil spills and dumping of plastics. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Northern fulmar is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.10 HERRING GULL

Distribution, Habitat, Abundance, and Predator and Prey

Herring gulls, *Larus argentatus,* are one of the most recognizable seabirds in Atlantic Canada. They have a circumboreal breeding range, and in eastern North America, breed along the Atlantic coast from Baffin Island to Cape Hatteras. During the winter, these birds are distributed fairly continuously along the Atlantic coast, and show a strong association with open fresh or salt water (Pierotti and Good, 1994). They breed predominantly on predator-free islands, but are also known to nest in cities or on rooftops near water (Pierotti and Good, 1994). Some individuals remain around breeding colonies in the winter, while others move south to tropical coastlines. These birds are most common close to land, although they are seen regularly offshore outside the breeding season (Brown, 1986). Large numbers of juveniles are known to associate with humpback whales in the Gulf of Maine and the Scotian Shelf when fish are driven to the surface (Pierotti, 1988).

Herring gulls are generalist predators, feeding on pelagic and intertidal marine invertebrates, fish, insects, other seabirds and their eggs. They opportunistically scavenge on carrion and human garbage. In Newfoundland, herring gulls primarily feed on mussels and other seabird species such as the Leach's storm-petrels during the pre-laying and incubation periods, then switch to capelin and other fish species when the chicks hatch (Pierotti and Good, 1994). Herring gulls are also known to scavenge at fishing vessels. Numbers of North American herring gull populations have increased significantly since 1900s as a result of decreased persecution on nesting grounds, increased access to refuge, and supplementary feeding at fishing vessels. Populations in eastern Canada, Maine, and Massachusetts, however, now appear to be on the decline (Pierotti and Good, 1994; Cotter et al., 2010), perhaps as a result of decreased fishing activity and increased competition from great black-backed gulls.

Population Structure Relative to Moratorium Area

Herring gulls are most common off the northeastern U.S. from October to May, with numbers peaking in March. There are also reports of a major offshore movement of herring gulls in the northeastern U.S. and Canadian Maritimes in the late fall and winter (Brown 1986, Pierotti and Good 1994). Herring gulls are observed on Georges Bank throughout the year (Table 4).

Life History, Location, and Timing

Birds first breed at 4-5 years of age. In Atlantic Canada, herring gulls typically lay their clutch of 2-3 eggs from mid-April to mid-May, but laying may continue through June (Brown, 1986). Both parents incubate for about a month, and both parents feed the chicks for 6-8 weeks. Young-of-the-year birds begin to leave the colony in the last half of July. Most adults remain near breeding colonies throughout the year, while young birds migrate to the southern portion of their range. Juvenile survivorship is relative low (50%) but, once they reach breeding age, survival estimates are closer to 90% (Pierotti and Good, 1994).

Known Vulnerabilities

As with most other marine bird species, herring gulls are susceptible to oil pollution at pelagic foraging areas. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Herring gull is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.11 GREAT BLACK-BACKED GULL

Distribution, Habitat, Abundance, and Predator and Prey

Great black-backed gulls, *Larus marinus,* occur only in the North Atlantic, and breed from North Carolina to Hudson Strait, with small populations scattered inland to the Great Lakes and west to northern Europe (Brown, 1986). Like the herring gulls, great black-backed gulls are most common close to land, but are regularly observed offshore outside the breeding season. Typically, they occur farther offshore than the herring gulls, and breed farther north. Birds breeding in southern Newfoundland move 50-100 km offshore to deeper water in late August, where they remain until April (Good, 1998). Different populations show varying degrees of migratory behaviour. Populations from Nova Scotia and New England tend to remain in the vicinity of breeding colonies, whereas birds from more northerly sites disperse southward (Good, 1998). Their wintering grounds extend as far south as Florida. During winter, they are often associated with coastal communities, roosting near ports, docks, dumps, and at estuaries (Good, 1998).

Great black-backed gulls are generalist predators, which prey on fish, marine invertebrates, mammals, insects, and other seabirds and their eggs. They also scavenge on human garbage, carrion, and are known to forage at offal from fishing vessels. At sea, they are often observed in small foraging groups. On Georges Bank, adults and juveniles have been observed feeding in pairs, and associated with feeding bluefin tuna (Pierotti, 1988). There is a recent increasing trend in great black-backed gull abundance as their range is expanding southward (see Good, 1998). Three censuses of gulls in Nova Scotia (1971, 1987, and 2002), however, show a 74% increase between 1971 and 1987, and a subsequent 31% decline between 1987 and 2002 (Cotter et al., 2010).

Population Structure Relative to Moratorium Area

In spring, immature birds and subadults are common in the shelf waters in the Gulf of Maine, Georges Bank, and southern New England. Band recoveries indicate that a significant proportion of great black-backed gulls winter in the Canadian Maritimes and northeastern U.S., on Georges Bank, and throughout the Gulf of Maine (Good, 1998).

Life History, Location, and Timing

Great black-backed gulls begin breeding at between 4-5 years of age. Females lay between 2-3 eggs, and both parents incubate and feed the chicks. Incubation lasts about a month, and chicks take their first flight at 45 days (Good, 1998). They don't typically leave the nest territory for another week or more, and some young will remain with one or both parents for several months after fledging. Fall dispersal from breeding colonies occurs mainly from September-October, and the return migration from March-April (Good, 1998). Like most seabirds, adult survivorship is relatively high.

Known Vulnerabilities

As with most other marine bird species, great black-backed gulls are susceptible to oil pollution at pelagic foraging areas. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

The great black-backed gull is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.12 BLACK-LEGGED KITTIWAKE

Distribution, Habitat, Abundance, and Predator and Prey

Black-legged kittiwakes, *Rissa tridactyla,* are one of North America's most widely distributed gulls. They have a circumpolar breeding distribution, although most breed in the Arctic and Subarctic. In Atlantic Canada, the largest colonies are found in eastern Newfoundland and the Gulf of St. Lawrence. During the breeding season, they remain relatively close to the coast, foraging within 50 km of the colony at upwellings or oceanic fronts (Baird, 1994). During migration, they are distributed offshore, often along the edge of sea ice. Black-legged kittiwakes winter from Newfoundland south to Georges Bank, feeding over a variety of water depths.

Black-legged Kittiwakes are piscivorous, catching their prey at the surface of the water. Prey species include capelin, sand lance, arctic cod, and pollock (Baird, 1994). They also feed on some invertebrates. The species is known to scavenge at fishing vessels. There is some indication that in the western Atlantic, the numbers of black-legged kittiwakes have increased. They have expanded their range south from Newfoundland to locations off Cape Breton Island, Nova Scotia, and into the Bay of Fundy and the Gulf of St. Lawrence coast in New Brunswick. In contrast, numbers at the largest colonies in Newfoundland appear to be in decline (Cotter et. al., 2010).

Population Structure Relative to Moratorium Area

Black-legged kittiwakes are most common off New England in January to March (Brown, 1986), although data suggest they occur on Georges Bank from October to April (Table 4). Returns from banding studies show that these birds are coming from breeding areas in Greenland, Iceland, and in the eastern Atlantic (see Brown, 1986), and are comprised of both adults and immature birds.

Life History, Location, and Timing

Like most seabirds, adults delay breeding until 4 or 5 years. Birds breeding in Newfoundland may begin nest-building as early as February and most young have fledged from the nest by mid- to late September (Baird, 1994). Their nests are built on cliff ledges and the females typically lay two and occasionally three eggs. Both adults take turns incubating the egg for approximately 25 days, and chicks are fed by both the male and female until they leave the nest between 35 and 50 days later, depending on their condition (Baird, 1994). Adults show strong fidelity to breeding sites. They have high annual survivorship (between 80-90%) and are long lived.

Known Vulnerabilities

As with most other marine bird species, black-legged kittiwakes are susceptible to oil pollution. An oil spill in Alaska was estimated to have killed thousands of kittiwakes. The spill also negatively impacted subsequent breeding productivity by destroying their prey base (Baird, 1994). Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

The black-legged kittiwake is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.13 NORTHERN GANNET

Distribution, Habitat, Abundance, and Predator and Prey

Northern gannets, *Morus bassanus,* are restricted to continental shelf waters on both sides of the Atlantic. In North America, they breed in just 6 colonies, 3 in Quebec, and 3 off the coast of Newfoundland. They breed in very dense colonies within foraging distance from their principal prey, the herring and mackerel, although adults may travel up to 500 km from the colony to forage (Mowbray, 2002). Post-breeding gannets forage in the Gulf of St. Lawrence, Strait of Belle Isle, nearshore waters off Labrador, and the east coast of Newfoundland before moving farther south for the winter (Mowbray, 2002). In winter, birds are more dispersed but remain mainly over shelf waters. In North America, their non-breeding range extends from New England south to Florida, and west along the Gulf of Mexico coast to Texas. In general, adults remain farther north than subadults during the winter (Mowbray, 2002).

Northern gannets feed primarily on surface-schooling fish including mackerel, herring, and capelin. To feed, they fly to a height of 10-40 m, turn, then use gravity to drop and plunge through the surface of the water, known as plunge-diving. They descend to a depth of 3-5 m, or even deeper if they swim to pursue their prey (Mowbray, 2002). Northern gannets were heavily persecuted before legal protection by the Migratory Birds Convention Act, and suffered declines due to the effects of dichlorodiphenyltrichloroethane (DDT) in the last century (Mowbray, 2002). As a result of legal protection and restrictions on the use of certain chemical substances, gannet populations in Atlantic Canada have increased dramatically (Chardine, 2000).

Population Structure Relative to Moratorium Area

Northern gannets are present on their breeding sites in the western Atlantic from about March through November. Southward migration begins in September, and by early to mid-October, large numbers of juveniles are on Georges Bank and adjacent waters (Veit and Petersen, 1993). Juveniles and subadults tend to travel farther south than adult birds, and remain longer in the wintering grounds than the adults. Adults appear to winter off the coast of New England. Northern gannets begin their northward migration in early March. Data show northern gannets on Georges Bank from March through May, travelling north to breeding colonies, and then again from October through December as they make their way south for the winter (Table 4).

Life History, Location, and Timing

Gannets remain at sea all year during their first 3 years. Age at first breeding is typically 4 or 5 years. At their main breeding colony in Newfoundland, Bonaventure Island, each breeding female lays a single egg in mid-May and the chick hatches in early July. Both adults take turns incubating the egg and feeding the chick. The average incubation period on Bonaventure Island is 44 days, and chicks fledge at 90 days, on average (Mowbray, 2002). The young may not leave the colony until October, or later (Brown, 1986). The peak southward migration passes Long Island, New York, in November, and birds begin to arrive in their wintering grounds in December (Brown 1986). Adults show strong fidelity to breeding sites, they have high annual survivorship, and an average life expectancy of 16 years (Mowbray, 2002).

Known Vulnerabilities

Northern gannets are not affected by oil spills to the degree that many other seabirds are due to their foraging method. They would be impacted by oil pollution, however, if that oil were to negatively affect their prey base. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Northern gannet is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

12.14 OTHER LARIDAE

Several other species from the family Laridae are observed on Georges Bank, including the ring-billed gull (*Larus delawarensis*), Iceland gull (*L. glaucoides*), glaucous gull (*L. hyperboreus*), and laughing gull (*Leucophaeus atricilla*). Ring-billed gulls breed throughout Atlantic Canada except in Nova Scotia. Small numbers are observed on the Bank during the spring and fall migration when the birds are moving between their breeding grounds and wintering areas along the eastern coast of the U.S. Arctic-breeding Iceland and glaucous gulls have occasionally been sighted on the Bank during the non-breeding season. Laughing gulls also are observed occasionally on the Bank during the winter before migrating south to breeding grounds located from central Maine to Georgia. Bonaparte's gulls (*L. philadelphia*) breed on lakes in the boreal forests of western Canada and Alaska, and are infrequently sighted on Georges Bank during the non-breeding season. All these gull species are more typically observed along the coastline than locations far from shore. They are all listed as 'least concern' by the IUCN.

Common terns (*Sterna hirundo*) are also occasionally observed on Georges Bank, while arctic terns (*S. paradisaea*) are less frequently sighted. Both species tend to occur closer to the coastline. They breed at colonies in coastal Nova Scotia and along the Gulf of Maine coast, and have been observed over the Bank during the spring, before the breeding season. Common terns spend their winter mainly along the coasts of Central and South America, while the arctic terns winter principally around Antarctica. The roseate tern (*S. dougallii*), which breeds at relatively few coastal locations from Long Island, New York to northern Nova Scotia, is listed as 'endangered' pursuant to SARA. This is a primarily coastal species and records on Georges Bank are rare. All three tern species are listed as 'least concern' by the IUCN.

12.15 OTHER BIRDS

A number of other marine birds have been observed on Georges Bank. Common loons (*Gavia immer*) cross the Bank in May and November when moving between breeding and non-breeding locations in northeastern North America. Three species of jaegers, all circumarctic breeders, have also been observed on the Bank, mainly in the spring and fall. Of these, pomarine jaegers (*Stercorarius pomarinus*) are the species most frequently sighted. Parasitic jaegers (*S. parasiticus*) are more commonly observed along the coast, and long-tailed jaegers (*S. longicaudus*) are only rarely recorded over the Bank (Powers and Brown, 1987). Great skuas (*S. skua*), which breed in the eastern North Atlantic, are sighted throughout the year, but are most common from October to March (Powers and Brown, 1987). South polar skuas (*S. maccormicki*) breed in the southern hemisphere, but have been observed on Georges Bank from May through October (Powers and Brown, 1987). These species are all listed as 'least concern' by the IUCN.

13.0 STATE OF KNOWLEDGE

While broad-scale understanding of the major physical drivers operating on Georges Bank have not changed since the previous review in 1999, there is a better understanding of the finer-scale details of how these processes operate, how they influence natural chemical and biological processes (e.g. nutrient flux, primary production and distribution of zooplankton), and how they might influence particle dispersion. The ability to observe and model these processes has also improved. There has been some investigation of how the chemical and physical environment of Georges Bank has changed over the past few decades (e.g. changes in surface temperatures and stratification), although the implications for the ecosystem as a whole are still being explored.

Georges Bank is known to be a very productive ecosystem, having high levels of primary production with comparatively low levels of zooplankton. Since 1999, advances have been made in the understanding of the role of microbes in this ecosystem (which assist with recycling of nutrients), as well as of the distribution, trends, and interactions of zooplankton. Changes in production and species composition have also been noted, with indications of a decline in spring cholorophyll and changes in zooplankton communities in response to the changing influences of water masses. Significant research since 1999 has also been conducted on corals in the Northeast Channel. In 2002, the Northeast Channel Coral Conservation Area was created to protect high densities of large, branching gorgonian corals.

There have been numerous new assessments of fish stocks present in the Georges Bank Moratorium Area, some of which are increasing after periods of lower abundance (e.g. haddock, yellowtail, herring), while others appear to remain at low levels (e.g. cod). There have also been new assessments of scallops, lobster, and Jonah crab, which indicate that scallop and lobster populations are increasing. Since 1999, there have been COSEWIC assessments or re-assessments of at least 12 species found on Georges Bank. New assessments and research have been conducted for both loggerhead and leatherback turtles since 1999, which help to provide new information on their use of Georges Bank and its surrounding areas. Seals are an increasing concern in the Gulf of Maine, particularly by fishermen, though limited work has been done specifically for Georges Bank.

Although the biological resources are well described and many of the linkages to the physical environment and other trophic levels have been identified, there remain many areas of incomplete understanding. Some new work has been done on the associations between groundfish and benthic habitats, but much is still unknown about specific habitat requirements and the locations of key feeding and spawning habitats of numerous species found on Georges Bank. For example, little is known about the breeding areas of fin whales and sei whales, leatherback turtles, black dogfish, and monkfish, while knowledge of the diets of cusk and juvenile loggerhead turtles are incomplete. One exciting new discovery, however, was the identification of a porbeagle shark pupping ground on Georges Bank.

There have been scientific advances in our understanding of the movements of many fish species in relation to Georges Bank, based on ongoing tagging studies, as well as advances in the understanding of the transport of larvae. Understanding of stock structure for many species, however, particularly the relationship between fish and invertebrates in Canadian and U.S. waters, is limited. The migration pattern of northern and southern components of northern shortfin squid, for example, is unknown. Similary, the stock structures of lobsters, Jonah crab, Atlantic halibut, witch flounder, and bluefin tuna are not well defined.

14.0 CONCLUSION

Georges Bank is a broad submarine bank located between the southwestern tip of Nova Scotia and Cape Cod, Massachusetts. The most southwesterly edge of Georges Bank is bounded at the Great South Channel and its northeasterly edge bounded at the Northeast Channel. The northern boundary separating this biogeographic area from the rest of the Gulf of Maine extends in a northeasterly direction from the Great South Channel. The Georges Bank Moratorium Area covers a diverse and productive marine ecosystem that has been the focus of many research initiatives over the past few decades. This has resulted in a good understanding of the individual physical and biological components of the system. There remains, however, many unanswered questions regarding the complex relationships between components, trophic dynamics, the interannual variations of populations, and the linkages with physical and chemical characteristics of the system. Predicting the response of the system to perturbations may be difficult.

The topographic and hydrographic features of the Bank result in high primary production, which in turn supports high levels of productivity and fish biomass. For example, the strong tidal forces on the Bank, coupled with topographic features, result in the establishment of an anticyclonic gyre that cause a partial retention of planktonic organisms. In addition, the fronts and gyre around the Bank facilitate the upwelling of nutrients onto the Bank and into the photic zone, leading to enhanced plankton production which supports a diverse food web. Perturbations that affect the timing and rate of primary and zooplankton production can affect the recruitment success of commercially-important species that are dependant on such production.

Georges Bank receives cold coastal waters through the Gulf of Maine, from the Scotian Shelf, and warm slope water through the Northeast Channel. With influences from both subpolar and subtropical water, the Bank acts as both the northern limit for many warm water species (e.g. bottlenose dolphin, and red crab) and the southern limit for many cold water species (e.g. sei whale). This results in a high level of diversity. Georges Bank also can serve as a source of organisms for surrounding areas. Strong, episodic forcing (e.g. winter storms) and warm-core ring entrainments result in an exchange of water and associated particles with surrounding water bodies, such as Browns Bank, and represent mechanisms for exchange from the Bank. For example, it is not known what percentage of lobster larvae is retained by the partial gyre of Georges Bank, although pelagic lobster larvae have been observed on the northern edge of the Bank, indicating some degree of off-Bank movement.

A distinctive characteristic of the Bank is its populations of bottom organisms, which are dominated by large filter feeders (e.g. scallops) that make up three-quarters of the biomass of the large, bottom dwelling organisms found in the area. Georges Bank also provides permanent or temporary habitat for many of the life stages of various fish, invertebrate, seabird, marine mammal, and turtle species, including bluefin tuna, swordfish, shearwater or phalaropes, corals and other benthos, as well as several species that have been listed or are being considered for listing pursuant to SARA. With the high diversity of organisms, Georges Bank is used year round as a feeding ground, spawning/nursery area, and/or migrations corridor for numerous species (see Appendix). For example, leatherback and loggerhead turtles commonly forage on the Bank in the summer and fall, while whales reach peak abundance in the spring and summer. The Bank is an important nursery ground for juvenile cod and haddock, but also acts as a migratory corridor for the North Atlantic Right Whale during its annual migration from wintering areas further south to feeding areas in Canadian waters. Last, seabirds are abundant on Georges Bank at all times of the year, although very few birds breed there. Georges Bank is an important destination for staging migrants, during their northward and southward movements, and also for over-wintering species.

REFERENCES

Albikovskaya, L.K. 1982. Distribution and abundances of Atlantic wolffish, spotted wolffish, and northern wolffish in the Newfoundland area. NAFO Sci. Coun. Studies. 3:29-32.

Annis, E.R. 2005. Temperature effects on the vertical distribution of lobster postlarvae (*Homarus americanus*). Limnology and Oceanography. 50:1972-1982.

ASMFC (Atlantic States Marine Fisheries Commission). 2009. Terms of Reference & Advisory Report for the American Lobster Stock Assessment Peer Review. Stock Assessment Peer Review Report No. 09-01 of the Atlantic States Marine Fisheries Commission.

Atema, J., Leavitt, D.F., Barshaw, D.E., and Cuomo. M.C. 1982. Effects of drilling muds on behaviour of the American lobster, *Homarus americanus,* in water column and substrate exposures. Canadian Journal of Fisheries and Aquatic Sciences. 39:675-690.

Avens, L., Taylor, J.C., Goshe, L.R., Jones, T.T., and Hastings, M. 2009. Use of skeletochronological analysis to estimate age of leatherback sea turtles *Dermochelys coriacea* in the western North Atlantic. Endangered Species Research. 8:165-177.

Backus, R.H. and Bourne, D.W (eds.). 1987. Georges Bank. MIT Press, Cambridge, Massachussetts. 593pp.

Baird, P.H. 1994. Black-legged Kittiwake (*Rissa tridactyla*). IN The Birds of North America, No. 92. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Baum, J.K., Myers, R.A., Kehlet, D.G., Worm, B., Harley, S.J., and Doherty, P.A. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science. 299:389-392.

Baumgartner, M.F., Cole, T.V.N., Campbell, R.G., Teegarden, G.J., and Durbin, E.G. 2003. Associations between North Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. Marine Ecology Progress Series. 264:155-166.

Beansland, D., Branton, R., and Mohen, R. 2000. Status of Monkfish in 4VWX5Zc. DFO Can. Stock Assess. Sec. Res. Doc. 2000/143.

Beauchamp, J., Bouchard, H., de Margerie, P., Otis, N., and Savaria, J.Y. 2009. Recovery Strategy for the blue whale (*Balaenoptera musculus*), Northwest Atlantic population, in Canada. DFO Species at Risk Strategy Series. Fisheries and Oceans Canada, Ottawa.

Beckett J.S. 1972. Biology of swordfish, *Xiphias gladius* L., in the Northwest Atlantic Ocean. NOAA Tech. Rep. NMFS SSRF-675. 103-106.

Begg, G.A., Hare, J.A., and Sheehan, D.D. 1999. The role of life history parameters as indicators of stock structure. Fisheries Research. 43:141-163.

Bigelow, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. Bulletin of the U.S. Bureau of Fisheries, Vol. XL, Part II. U.S. Government Printing Office, Washington, D.C.

Bigelow, H.B. and Schroeder, W.C. 1953. Fishes of the Gulf of Maine. Fishery Bulletin. 74:1-577.

Bisagni, J.J. 2000. Estimates of vertical heat flux and stratification from Southern Georges Bank, interannual variability, 1985–1995. Continental Shelf Research. 20:211-234.

Bisagni, J.J. 2003. Seasonal variability of nitrate supply and potential new production in the Gulf of Maine and Georges Bank regions. Journal of Geophysical Research. 108:8015. 22pp.

Bisagni, J.J. and Smith, P.C. 1998. Eddy-induced flow of Scotian Shelf water across the Northeast Channel, Gulf of Maine. Continental Shelf Research. 18:515-539.

Black, G.A.P., Mohn, R.K., Robert, G., and Tremblay, M.J. 1993. Atlas of the biology and distribution of the sea scallop Placopecten magellanicus and Iceland scallop Chlamys islandica in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1915. 40pp.

Block, B.A.., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Seitz, A., Walli, A., and Fudge, D. 2001. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. Science. 293:1310-1314.

Block, B.A., Teo, S.L.H., Walli, A. Boustany, A., Stokesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H., and Williams, T.D. 2005. Electronic tagging and population structure of Atlantic bluefin tuna. Nature. 434:1121-1127.

Boudreau, P.R., Gordon, D.C.Jr., Harding, G.C., Loder, J.W., Black, J., Bowen, W.D., Campana, S., Cranford, P.J., Drinkwater, K.F., Van Eeckhaute, L., Gavaris, S., Hannah, C.G., Harrison, G., Hunt, J.J. McMillan, J., Melvin, G.D., Milligan, T.G., Muschenheim, D.K., Neilson, J.D., Page, F.H., Pezzack, D.S., Robert, G., Sameoto, D., and Stone, H. 1999. The Possible Environmental Impacts of Petroleum Exploration Activities on the Georges Bank Ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 2259. vi + 106pp.

Bourne, N. 1964. Scallops and the offshore fishery of the Maritimes. Fish. Res. Board of Can. Bull. No. 145.

Bowen, W.D., Lawson, J.W., and Beck, B. 1993. Seasonal and geographic variation in the species composition and size of prey consumed by grey seals (*Halichoerus grypus*) on the Scotian Shelf. Canadian Journal of Fisheries and Aquatic Sciences. 50:1768-1778.

Bowen, W.D., Ellis, S.L., Iverson, S.J., and Boness, D.J. 2003. Maternal and newborn life history traits during periods of contrasting population trends: Implications for explaining the decline of harbour seals (*Phoca vitulina*), on Sable Island. Journal of Zoology, London. 261:155-163.

Bowen, W.D., McMillan, J.I., Lidgard, D., and Blanchard, W. 2007. Continued reduction in population growth rates of grey seals at Sable Island. DFO. Can. Sco. Advis. Sec. Res. Doc. 2007/087.

Brand, A.R. 2006. Scallop ecology: distributions and behaviour. IN Scallops: Biology, Ecology and Aquaculture, Second Edition. Shumawy S.E. and Parsons, G.J. (eds). Elsevier, New York. 651-744.

Brawn V.M. 1961. Reproductive behaviour of the cod (*Gadus callarias* L.). Behaviour. 18:177-198.

Breed, G.A., Jonsen, I.D., Myers, R.A., and Bowen, W.D. 2009. Sex specific, seasonal foraging tactics of adult grey seals (*Halichoerus grypus*) revealed by state-space analysis. Ecology. 90:3209-3221.

Breeze, H., D.G. Fenton, R.J. Rutherford, and M.A. Silva. 2002. The Scotian Shelf: An Ecological Overview for Ocean Planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393. x + 259pp.

Brink, K.H., Limeburner, R., and Beardsley, R.C. 2003. Properties of flow and pressure over Georges Bank as observed with near-surface drifters. Journal of Geophysical Research. 108:8001. 17pp.

Brodziak, J.T. 1995. Long-finned squid. IN Status of the Fishery Resources off the Northeastern United States for 1994. Conservations and Utilization Division, Northeast Fisheries Science Center (ed.). NOAA Tech. Mem. NMFS-NE-108.

Brodziak, J.T. 2005. Essential fish habitat source document: Haddock, *Melanogrammus aeglefinus*, life History and habitat characteristics, 2nd ed. NOAA Tech. Mem NMFS-NE-196. 74pp.

Brodziak, J.T. and Macy, W.K.. 1996. Growth of long-finned squid, Loligo pealei, in the Northwest Atlantic. Fishery Bulletin. 94:212-236.

Brown, R.G.B. 1986. Revised atlas of eastern Canadian seabirds. I. Shipboard surveys. Canadian Wildlife Service, Ottawa, Ontario.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E., and Davis, T. 1975. Atlas of eastern Canadian seabirds. Canadian Wildlife Service, Ottawa, Ontario.

Brown, S.K., Mahon, R., O'Boyle, R., Zwanenburg, K. Buja, K., Claflin, L., Atkinson, B., Howell, G., Sinclair, M., and Monaco, M. 1996. East coast of North America groundfish: initial explorations of biogeography and species assemblages. Strategic Environmental Assessments Division, National Oceanic and Atmospheric Administration, Silver Spring, Maryland and Marine Fish Division, Department of Fisheries and Oceans, Dartmouth, Nova Scotia.

Brown, H., Bollens, S.M., Madin, L,P., and Horgan, E.F. 2005. Effects of warm water intrusions on populations of macrozooplankton on Georges Bank, Northwest Atlantic. Continental Shelf Research. 25:143-156.

Brown, M.W., Fenton, D., Smedbol, K., Merriman, C., Robichaud-Leblanc, K., and Conway, J.D. 2009. Recovery Strategy for the North Atlantic Right Whale (*Eubalaena glacialis*) in Atlantic Canadian Waters [Final]. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa.

Bruno, I., Costas, G., González, C., and Paz, X. 2000. Feeding chronology of yellowtail flounder (*Limanda feruginea)* and American plaice (*Hippoglossoides platessoides)* on Grand Bank (NAFO Division 3N). NAFO Sci. Coun. Studies 33. 103–116.

Buckley, L.J. and Durbin, E.G. 2006. Seasonal and inter-annual trends in the zooplankton prey and growth rate of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) larvae on Georges Bank. Deep-Sea Research II 53:2758-2770.

Butman, B. and Beardsley, R.C. 1987. Physical oceanography. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 88-98.

Butman, B., Loder, J.W., and Beardsley, R.C. 1987. The seasonal mean circulation: observation and theory. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 125-138.

Cadrin, S.X. 2003. Stock structure of yellowtail flounder off the northeastern United States. University of Rhode Island Doctoral Dissertation.

Cadrin, S.X. 2006. Yellowtail flounder tagging study – 2006 Annual Report. Northeast Consortium Annual Report.

Cadrin, S.X. and Moser, J. 2006. Partitioning on-bottom and off-bottom behaviour: A case study with yellowtail flounder off New England. International Council for the Exploration of the Sea Report CM 2006/Q. 14pp.

Cadrin, S.X., Westwood, A., Alade, L., Keith, N., Rountree, R., Martins, C., Kessler, R., Jones, D., Valliere, A., King, J., Boardman, J., Stone, H., and New England Fishermen. 2004. Movement of yellowtail flounder: A cooperative tagging study. Ninth Flatfish Biology Conference, December 1-2, 2004, West Brook, Connecticut. NEFSC Ref. Doc. 04-13.

Campana, S.E., Gibson, A.J.F., Fowler, M., Dorey, A., and Joyce, W. 2010. Population dynamics of porbeagle in the northwest Atlantic, with an assessment of status to 2009 and projections for recovery. Collect. Vol. Sci. Pap. ICCAT. In press.

Cargnelli, L., Griesbach, S., and Morse W. 1999. Essential fish habitat source document: Atlantic halibut, *Hippoglossus hippoglossus*, life history and habitat characteristics. NOAA Tech. Memo. NMFS-NE-125. 26pp.

Carruthers, E.H., Neilson, J.D., Waters, C., and Perley, P. 2005. Long term changes in the feeding of *Pollachius virens* on the Scotian Shelf: responses to a dynamic ecosystem. Journal of Fish Biology. 66:327-347.

Carter, J.A. and Steele, D.H. 1982. Stomach contents of immature lobsters (*Homarus americanus*) from Placentia Bay, Newfoundland. Canadian Journal of Zoology. 60:337-347.

Casey, J. and Myers, R.A. 1998. Near extinction of a large, widely distributed fish. Science. 281:690-692.

Casper, B.M., Domingo, A., Gaibor, N., Heupel, M.R., Kotas, E., Lamónaca, A.F., Pérez-Jimenez, J.C., Simpfendorfer, C., Smith, W.D., Stevens, J.D., Soldo, A., and Vooren, C.M. 2005. *Sphyrna zygaena*. IN IUCN 2009, IUCN Red List of Threatened Species, Version 2009.2. Website <www.iucnredlist.org> (cited 2 February 2010).

Cassoff, R.M., Campana, S.E., and Myklevoll, S. 2007. Changes in baseline growth and maturation parameters of Northwest Atlantic porbeagle, Lamna nasus, following heavy exploitation. Canadian Journal of Fisheries and Aquatic Sciences. 64:19-29.

CETAP (Cetacean and Turtle Assessment Program). 1982. A characterization of marine mammals and turtles in the mid- and North-Atlantic area of the U.S. outer continental shelf, Rep. No. NYIS PB83-243289. Final Report to Bureau of Land Management, Springfield, Virginia.

Chardine, J.W. 2000. Census of Northern Gannet colonies in the Atlantic Region in 1999. Tech. Report No. 361. Canadian Wildlife Service, Atlantic Region.

Chen, C., Xu, Q., Beardsley, R.C., and Franks, P.J.S. 2003a. Model study of the cross-frontal water exchange on Georges Bank: A three-dimensional Lagrangian experiment. Journal of Geophysical Research. 108:3142.

Chen, C., Schlitz, R.J., Lough, R.G., Smith, K.W., Beardsley, R.C., and Manning, J.P. 2003b. Wind-induced, cross-frontal exchange on Georges Bank: A mechanism for early summer on-bank biological particle transport. Journal of Geophysical Research. 108:8011. 11pp.

Churchill, J.H., Manning, J.P., and Beardsley, R.C. 2003. Slope water intrusions onto Georges Bank. Journal of Geophysical Research. 108:8012. 16pp.

Clark, D. and Emberley, J. 2009. Update of the 2008 summer Scotian Shelf and Bay of Fundy research vessel survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/017.

Clark, D., Emberley, J., Clark, C., and Peppard, B. 2010. Update of the 2009 Summer Scotian Shelf and Bay of Fundy Research Vessel Survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/008.

Cogswell, A.T., Kenchington, E.L.R., Lirette, C.G., MacIsaac, K., Best, M.M., Beazley, L.I., and Vickers, J. 2009. The current state of knowledge concerning the distribution of coral in the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci. 2855. v + 66 pp.

Cohen, E.B. and Grosslein, M.D. 1987. Production on Georges Bank compared with other shelf ecosystems. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds). MIT Press, Cambridge, Massachusetts. 383-391.

Collie, J.S., Escanero, G.A., and Valentine, P.C. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Marine Ecology Progress Series. 155:159-172.

Cohen, R.E. and Lough, R.G. 1983. Prey field of larval herring *Clupea harengus* on a continental shelf spawning area. Marine Ecology Progress Series. 10:211-222.

Colette, B.B. and Klein-MacPhee G (eds.). 2002. Bigelow and Shroeder's fishes of the Gulf of Maine, 3rd ed. Smithsonian Institution Press, Washington, D.C.

Collie, J.S. 1987. Food consumption of yellowtail flounder in relation to production of its benthic prey. Marine Ecology Progress Series. 36:205-213.

Collie, J.S., Escanero, G.A., and Valentine, P.C. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Marine Ecology Progress Series. 155:159-172.

Collie J.S., Escanero, and P.C. Valentine. 2000. Photographic evaluation of the impacts of bottom fishing on benthic epifauna. ICES Journal of Marine Science. 57:987-1001.

Collie, J.S., Hermsen, J.M., Valentine, P.C., and Almeida, F.P. 2004. Effects of fishing on gravel habitats: assessment and recovery of benthic megafauna on Georges Bank. IN Benthic Habitats and the Effects of Fishing. Barnes, P. and Thomas, J. (eds.). American Fisheries Society, Bethesda, Maryland.

Collie, J.S., Hermsen, J.M., and Valentine, P.C. 2009. Recolonization of gravel habitats on Georges Bank (Northwest Atlantic). Deep Sea Research II. 56:1847-1855.

Colton, J.B.Jr., Temple, R.F., and Honey, K.A. 1962. The occurrence of oceanic copepods in the Gulf of Maine–Georges Bank area. Ecology. 43:66-171.

Conant, T.A., Dutton, P.H., Eguchi, T., Epperly, S.P., Fahy, C.C., Godfrey, M.H., MacPherson, S.L., Possardt, E.E., Schroeder, B.A., Seminoff, J.A., Snover, M.L., Upite, C.M., and Witherington, B.E. 2009. Loggerhead sea turtle *(Caretta caretta)* 2009 status review under the U.S. Endangered Species Act. Report of the Loggerhead Biological Review Team to the National Marine Fisheries Service.

Cooper, R.A. and Uzmann, J.R. 1980. Ecology of juvenile and adult homarus. IN The Biology and Management of Lobsters, Vol 2: Ecology and Management. Cobb, J.S. and Phillips, B.F. (eds.). Academic Press, New York. 390pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2000. COSEWIC assessment and status report on the Atlantic wolffish *Anarhichas lupus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2001. COSEWIC assessment and status report on the leatherback turtle *Dermochelys coriacea* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2002. COSEWIC assessment and update status report on the blue whale *Balaenoptera musculus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003a. COSEWIC assessment and status report on the cusk, *Brosme brosme* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003b. COSEWIC assessment and update status report on the North Atlantic right whale *Eubalaena glacialis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2004. COSEWIC assessment and status report on the porbeagle shark *Lamna nasus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2005a. COSEWIC assessment and status report on the winter skate Leucoraja ocellata in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2005b. COSEWIC assessment and update status reported on the fin whale Balaenoptera physalus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006a. COSEWIC assessment and status report on the shortfin mako *Isurus oxyrinchus* (Atlantic population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006b. COSEWIC assessment and status report on the blue shark *Prionace glauca* (Atlantic and Pacific populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006c. COSEWIC assessment and status report on the white shark *Carcharodon carcharias* (Atlantic and Pacific populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006d. COSEWIC assessment and update status report on the harbour porpoise *Phocoena phocoena* (Northwest Atlantic population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006e. COSEWIC assessment and update status report on the Sowerby's beaked whale *Mesoplodon bidens* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2010 (In press). COSEWIC assessment and status report on the deepwater Redfish/Acadian redfish complex *Sebastes mentella* and *Sebastes fasciatus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa

Cotter, R.C., Rail, J.-F., Boyne, A.W., Chaulk, K.G., Robertson, G.J., and Weseloh, D.V. 2010. Population status, distribution and trends of gulls and kittiwakes nesting in coastal Atlantic Canada and along the Great Lakes-St. Lawrence system of Ontario and Quebec. Canadian Wildlife Service Occasional Paper.

Cranford, P.J., Gordon, D.C.Jr., Lee, K., Armsworthy, S.L., and Tremblay, G.H. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Marine Environmental Research. 48:225-256.

Cranford, P.J., Gordon, D.C.Jr., Hannah, C.G., Loder, J.W., Milligan, T.G., Muschenheim, K., and Shen, Y. 2003. Modelling potential effects of petroleum exploration drilling on northeastern Georges Bank scallop stocks. Ecological Modeling. 166:19-39.

Csanady, G.T. and Magnell, B.A. 1987. Mixing processes. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 163-169.

Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Advances in Marine Biology. 26:249-294.

Dale, A.C., Ullman, D.S., Barth, J.A., and Hebert, D. 2003. The front on the northern edge of Georges Bank in Spring. Part I: Tidal and Subtidal Variability. Journal of Geophysical Research. 108:8009. 18pp.

Davis, C.S. 1984. Interaction of a copepod population with the mean circulation on Georges Bank. Journal of Marine Research. 42:573-590.

Davis, C.S. 1987. Zooplankton life cycles. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 256-267.

Dawe, E.G. and Beck, C.P. 1985. Distribution and size of short-finned squid (*Illex illecebrosus*) larvae in the Northwest Atlantic from winter surveys in 1969, 1981 and 1982. Journal of Northwest Atlantic Fishery Science. 6:43-55.

Dawe, E.G. and Hendriskson, L.C. 1998. A review of the biology, population dynamics, qnd exploitation of short-finned squid in the northwest Atlantic Ocean in relation to assessment and management of the resource. Northwest Atlantic Fisheries Organization (NAFO) Science Council Research Document. 98/59.

Derby, J.G.S and Capuzzo, J.M. 1984. Lethal and sublethal toxicity of drilling fluids to larvae of the American lobster *(Homarus americanus).* Canadian Journal of Fisheries and Aquatic Sciences. 41:1334-1340.

DFO (Fisheries and Oceans Canada). 1996a. Scotian Shelf Sand Lance. DFO Sci. Stock Stat. Rep. 1996/77E. 2pp.

DFO (Fisheries and Oceans Canada). 1996b. Blue Shark. DFO Atl. Fish. Res. Doc. 96/34E. 3pp.

DFO (Fisheries and Oceans Canada). 1998. Scotian Shelf Red Crab. DFO Sci. Stock Stat. Rep. C3-11. 6pp.

DFO (Fisheries and Oceans Canada). 2000. Status of Redfish Stocks in the Northwest Atlantic: Redfish in Units 1, 2 and in Division 3O. DFO Sci. Stock Stat. Rep. A1-01. 21pp.

DFO (Fisheries and Oceans Canada). 2002a. Monkfish on the Scotian Shelf and the Northeast Georges Bank (Div. 4VWX and 5Zc). DFO Sci. Stock Stat. Rep. A3-30. 7pp.

DFO (Fisheries and Oceans Canada). 2002b. Updates on selected Scotian Shelf groundfish stocks in 2002. DFO Sci. Stock Stat. Rep. A3-35. 30pp.

DFO (Fisheries and Oceans Canada). 2002c. Wolffish on the Scotian Shelf and in the Bay of Fundy (Div 4VWX and Div. 5YZe). DFO Sci. Stock Stat. Rep. 7pp.

DFO (Fisheries and Oceans Canada). 2002d. Canadian Atlantic Pelagic Shark Integrated Fisheries Management Plan (2002-2007). DFO Integrated Fisheries Management Plan. Website < http://www.dfo-mpo.gc.ca/communic/fish_man/ifmp/shark-requin/index_e.htm> (cited 26 November 2010)>

DFO (Fisheries and Oceans Canada) 2004a. Atlantic Mackerel of the Northwest Atlantic in 2003. DFO Can. Sci. Advis. Sec. Stock Status Rep. 2004/018. 12pp.

DFO (Fisheries and Oceans Canada). 2004b. Biology, fishery and stock status of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Candian waters. DFO Can. Sci. Advis. Sec. Res. Doc 2004/094. 33pp.

DFO (Fisheries and Oceans Canada). 2005. Stock Assessment Report in NAFO Subareas 3-6 Porbeagle Shark. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/044. 11pp.

DFO (Fisheries and Oceans Canada). 2006a. 2005 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine – Bay of Fundy, Scotian

Shelf, and the Southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.2006/048. 18pp.

DFO (Fisheries and Oceans Canada). 2006b. Assessment of the Recovery Poential of Shortfin Mako Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/091. 24pp.

DFO (Fisheries and Oceans Canada). 2006c. Recovery Potential Assessment Report of Shortfin Mako Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/051. 9pp.

DFO (Fisheries and Oceans Canada). 2006d. Recovery potential assessment report on white sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/052. 6pp.

DFO. 2007a. Assessment of Spiny Dogfish in Atlantic Canada. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/046. 23pp.

DFO (Fisheries and Oceans Canada). 2007b. Stock Structure, life history, fishery and abundance indices for spiny dogfish (Squalus acanthias) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/089. 136pp.

DFO (Fisheries and Oceans Canada). 2008a. Assessment of Georges Bank Scallops (*Placopecten magellanicus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/045. 12pp.

DFO (Fisheries and Oceans Canada). 2008b. Assessment of the Atlantic mackerel stock for the Northwest Atlantic (Subareas 3 and 4) in 2007. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/041. 15pp.

DFO. 2008c. Recovery Potential Assessment for Cusk (*Brosme brosme*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/024. 11pp.

DFO (Fisheries and Oceans Canada). 2008d. Status of basking Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc 2008/004. 67pp.

DFO (Fisheries and Oceans Canada). 2008e. Stock assessment of Northewest Atlantic grey seals (Halichoerus grypus). DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/056. 10pp.

DFO (Fisheries and Oceans Canada). 2009a. 2008 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine - Bay of Fundy and on the Scotian Shelf. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/054. 18pp.

DFO (Fisheries and Oceans Canada). 2009b. Assessment of Jonah Crab in Lobster Fishing Area 41 (4X + 5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/034. 11pp.

DFO (Fisheries and Oceans Canada). 2009c. Pollock in Div. 4VWX+5. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/025. 13pp.

DFO (Fisheries and Oceans Canada). 2009d. DFO. 2009. Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/036. 12pp.

DiBacco, C., Robert, G., and Grant, J. 1995. Reproductive cycle of the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), on northeastern Georges Bank. Journal of Shellfish Research. 14:59-69.

Dickinson, J.J. and Wigley, R.L. 1981. Distribution of gammaridean Amphipoda (Crustacea) on Georges Bank. National Oceanic and Atmospheric Administration Tech. Rep., National Mar. Fish. Serv. Spec. Sci. Rep. Fish. 746.

Drinkwater, K.F. and Loder, J.W. 2001. Near-surface horizontal convergence and dispersion near the tidal-mixing front on northeastern Georges Bank. Deep-Sea Research II. 48:311-339.

Drinkwater, K.F., Mountain, D.B., and Herman, A. 1998. Recent changes in the hydrography of the Scotian Shelf and Gulf of Maine – A return to conditions of the 1960s?. NAFO SCR Doc. No. 37, Serial No. N3024.

Durbin, E.G. and Casas, M.C. 2006. Abundance and spatial distribution of copepods on Georges Bank during the winter/spring period. Deep-Sea Research II. 53:2537-2569.

Durbin, E. G., Campbell, R. G., Casas, M.C., Ohman, M.D., Niehoff, B., Runge, J.A., and Wagner, M. 2003. Interannual variation in phytoplankton blooms and zooplankton productivity and abundance in the Gulf of Maine during winter. Marine Ecology Progress Series. 254:81-100.

Edds-Walton, P. L. and Finneran, J.J. 2006. Evaluation of evidence for altered behavior and auditory deficits in fishes due to human-generated noise sources. SSC Tech. Rep. SSC. San Diego, California. 54pp.

Edwards, R.L. 1968. Fishery resources of the North Atlantic area. IN The Future of the Fishing Industry of the United States, Volume 4. Gilbert, D.W. (ed.). University of Washington Publications in Fisheries, Seattle, Washington. 52-60.

Elner, R.W. and Campbell, A. 1987. Natural diets of lobster Homarus americanus from barren ground and macroalgal habitats off southwestern Nova Scotia, Canada. Marine Ecology Progress Series 37:131-140.

Etnoyer, P. and Morgan, L. 2003. Occurrences of habitat-forming deep sea corals in the Northeast Pacific Ocean. . Technical Report, NOAA Office of Habitat Conservation, Marine Biology Conservation Institute. 31pp.

Finstad, J.L. and Nordeide, J.T. 2004. Acoustic repertoire of spawning cod, *Gadus morhua*. Environmental Biology of Fishes. 40:427-433.

Fish, M.P. and Mowbray, W.H. 1970. Sounds of Western North Atlantic Fishes. John Hopkins Press, Baltimore. 231pp.

Flagg, C.N. 1987. Hydrographic structure and variability. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 108-124.

Flagg, C.N., Magnell, B.A., Frye, D., Cura, J.J., McDowell, S.E., and Scarlet, R.I. 1982. Interpretation of the physical oceanography of Georges Bank. Report prepared for U.S. Dept. of Interior, Bureau of Land Management (Report prepared by EG&G Environmental Consultants, Waltham, Massachussetts).

Fosså, J.H., Mortensen, P. and Furevik, D. 2002 The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia. 471:1-12.

Fowler, S.L., Cavanagh, R.D., Camhi, M., Burgess, G.H., Cailliet, G.M., Fordham, S.V., Simpfendorfer, C.A., and Musick, J.A.. 2005. Sharks, Rays and Chimaeras: The Status of the Chondrichthyan Fishes. Status Survey. IUCN/SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

Frank, K.T., Petrie, B., Shackell, N.L., Choi, J.S. 2006. Reconciling differences in trophic control in mid-latitude marine ecosystems. Ecological Letters. 9:1096-1105.

Franks, P.J.S. and Chen, C. 2001. A three-dimensional prognostic model study of the ecosystem over Georges Bank and adjacent coastal regions, Part II: coupled biological and physical model. Deep Sea Research II. 48:457-482.

Friedland, K. and Hare, J. 2007. Long-term trends and regime shifts in sea surface temperature on the Continental Shelf of the northeast United States. Continental Shelf Research. 27:2313-2328.

Fudge, S.B. and Rose, G.A. 2009. Passive- and active-acoustic properties of a spawning Atlantic cod (*Gadus morhua*) aggregation. ICES Journal of Marine Science. 66:1259-1263.

Fujiwara, M. and Caswell, H. 2001. Demography of the endangered North Atlantic right whale. Nature. 414:537-541.

Gaichas, S., Skaret, G., Falk-Petersen, J., Link, J., Overholtz, W., Megrey, B., Gjoesaeter, H., Stockhausen, W., Dommasnes, A., Friedland, K., and Aydin, K. 2009. A comparison of community and trophic structure in five marine ecosystems based on energy budgets and system metrics. Progress in Oceanography. 81:47-62.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. Nature. 238:441-443.

Garrett, C.J.R., Keeley, J.R., and Greenberg, D.A. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean. 16:403-423.

Garrison, L.P. and Link, J.S. 2000a. Dietry guild structure of the fish community in the Northeast United States continental shelf ecosystem. Marine Ecology Progress Series. 202:231-240.

Garrison, L.P. and Link, J.S. 2000b. Fishing effects on spatial distribution and trophic guild structure of the fish community in the Georges Bank region. ICES Journal of Marine Science. 57:723-730.

Gaston, A.J. and Hipfner, J.M. 2000. Thick-billed Murre (*Uria lomvia*). IN The Birds of North America, No. 497. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Gavaris, S., O'Boyle, R., and Overholtz, W. 2005. Proceedings of the Transboundary Resources Assessment Committee (TRAC) benchmark review of stock assessment models for the Georges Bank yellowtail flounder stock. TRAC Proceedings 2005/01. 40pp.

Gedamke, T., DuPaul, W.D., and Musick, J.A. 2005. Observations on the life history of the barndoor skate, *Dipturus laevis*, on Georges Bank (Western North Atlantic). Journal of Northwest Atlantic Fishery Science. 35:67-78.

George, D.A. and Hill, P.S. 2008. Wave climate, sediment supply and the depth of the sand-mud transition: A global survey. Marine Geology. 254:121-128.

Gilbert, C.S., Gentleman, W.C., Johnson, C.L., DiBacco, C., Pringle, J.M., and Chen, C.S. 2010. Modeling transport of Sea Scallop (*Placopecten magellanicus*) larvae on Georges Bank: Influence of behavior and spawning seasonality. Progress in Oceanography. In press.

Golet, W.J. 2010. Somatic Condition, Growth and Distribution of Atlantic Bluefin Tuna (Thunnus thynnus) in the Gulf of Maine. Doctoral Dissertation, University of New Hampshire, New Hampshire.

GOMA (Gulf of Maine Area: Census of Marine Life). 2010. Georges Bank and Great South Channel. Website <www.gulfofmaine-census.org/about-the-gulf/physical-characteristics/physioregions> (cited 1 November 2010).

Good, T.P. 1998. Great black-backed gull (*Larus marinus*). IN The Birds of North America, No. 330. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Gordon, D.C. (ed). 1988. An Assessment of the Possible Environmental Impacts of Exploratory Drilling On Georges Bank Fishery Resources. Can. Tech. Rep. Fish. Aquat. Sci. No. 1633: iv + 31pp.

Gordon, D., and Kenchington, E. 2007. Deep-water corals in Atlantic Canada: a review of DFO research (2001-2003). Proceedings of the Nova Scotian Institute of Science. 44:27-50.

Greene, C. H. and Pershing, A.J. 2007. Climate drives sea change. Science. 315:1084-1085.

Haapkla, J., Ramade, F., and Salvato B. 2007. Oil pollution on coral reefs: A review of the state of knowledge and management needs. Life and Environment. 57:91-107.

Hahm, W. and Langton, R. 1984. Prey selection based on predator/prey weight ratios for some northwest Atlantic fish. Marine Ecology Progress Series. 19:1-5.

Hammill, M.O. and Stenson, G.B. 2000. Estimated pey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. Journal of Northwest Atlantic Fishery Science. 26:1-23.

Hanke, A.R., Page, F.H., and Neilson, J. 2001. Distribution of pollock (*Pollachius virens*) eggs and larvae on the Scotian Shelf, eastern Gulf of Maine, Bay of Fundy and eastern Georges Bank. Can. Tech. Fish. Aqua. Sci. 2345. 118pp.

Hannah, C.G., Loder, J.W., and Shen, Y. 1996. Shear dispersion in the benthic boundary layer. IN Estuarine and Coastal Modeling: Proceedings of the 4th International Conference. Spaulding, M.L. and Cheng, R.T. (eds.). ASCE, New York. 454-465.

Hannah, C.G., Naimie, C.E., Loder, J.W., and Werner, F.E. 1998. Upper-ocean transport mechanisms from the Gulf of Maine to Georges Bank, with implications for Calanus supply. Continental Shelf Research. 17:1887-1911.

Harding, G.C., Pringle, J.D., Vass, W.P., Pearre, S.Jr., and Smith, S.J. 1987. Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. Marine Ecology Progress Series. 41:29-41.

Harding, G.C., Drinkwater, K.F., Pringle, J.D., Fraser, A.J., Prena, J., Pearre, S.Jr., Perry, R.I.Jr., and Vass W.P. 1995. Studies on the effect of the frontal zone on the northern face of Georges Bank, Gulf of Maine, on larval lobster and plankton distribution. ICES, Copenhagen (Denmark). ICES-CM-1990/L:8.

Harding, G.C., Drinkwater, K.F., Hannah, C.G., Pringle, J.D., Prena, J., Loder, J.W., Pearre, S.Jr., and Vass. W.P. 2005. Larval lobster (*Homarus americanus*) distribution and drift in the vicinity of the Gulf of Maine offshore banks and their probable origins. Fisheries Oceanography. 14:112-137.

Hareide, N.R. and Garnes, G. 2001. The distribution and catch rates of deep water fish along the Mid-Atlantic Ridge from 43 to 61 degrees N. Fisheries Research. 51:297-310.

Harris, L.E. and Hanke, A.R. 2010. Assessment of the Status, Threats and Recovery Potential of Cusk (*Brosme brosme*). DFO Can. Sci. Adv. Sec. Res. Doc. 2010/004. 29pp.

Harris, L.E., Comeau, P.A., and Clark, D.S. 2002. Evaluation of Cusk (*Brosme brosme*) in Canadian Waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/104. 40pp.

Harrison, P. 1988. Seabirds: An identification guide. Houghton Mifflin Harcourt, London. 448pp.

Harrison, G., Johnson, C., Head, E., Spry, J., Pauley, K., Maass, H., Kennedy, M., Porter, C., and Soukhovtsev, V. 2009. Optical, chemical and biological oceanographic conditions in the Maritimes region in 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/054. 61pp.

Hatch, S.A. 1987. Adult survival and productivity of Northern Fulmars in Alaska. Condor. 89:685-696.

Hatch, S.A. and Nettleship, D.N. 1998. Northern fulmar (*Fulmarus glacialis*). IN The Birds of North America, No. 361. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Hawkins, A.D. 1986. Underwater sound and fish behaviour. IN Behaviour of Teleost Fishes. Pitcher, T.J. (ed.). Croom Helm, London. 114-151.

Hawkins, A.D. and Rasmussen, K.J. 1978. The sounds of gadoid fish. Journal of the Marine Biological Association of the United Kingdom. 58:891-911.

Hawkins, A.D. and Amorim, M.C.P. 2000. Spawning sounds of the male haddock, *Melanogrammus aeglefinus*. Environmental Biology of Fishes. 59:29-41.

Hawkins, A.D., Chapman, C.J., and Symonds, D.Y. 1967. Spawning of haddock in captivity. Nature 215:923-925.

Hendrickson, L.C. 2004. Population biology of northern shortfin squid (*Illex illecebrosus*) in the Northwest Atlantic Ocean and initial documentation of a spawning area. ICES Journal of Marine Science. 61:252-266.

Hendrickson, L.C. and Holmes, E.M. 2004. Essential fish habitat source document: northernshortfin squid, Illex illecebrosus, life history and habitat characteristics, 2nd Edition. NOAA Tech. Memo. NMFS-NE-191. 46pp.

Hendrickson, L.C. and Jacobson, L. 2006. Longfin Inshore Squid *(Loligo pealeii).* Website <http://www.nefsc.noaa.gov/sos/spsyn/iv/lfsquid> (cited 2 February 2010).

Hobbie J.E., Novitsky, T.J., Rublee, P.A., Ferguson, R.L., and Palumbo, A.V. 1987. Microbiology. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 247-251.

Horne, E.P.W., Loder, J.W., Harrison, W.G., Mohn, R., Lewis, M.R., Irwin, B., and Platt, T. 1989. Nitrate supply and demand at the Georges Bank tidal front. Scientia Marina. 53:145-158.

Houghton, R. and Fairbanks, R. 2001. Water sources for Georges Bank. Deep Sea Research II. 48:95-114.

Houser, D.S., Howard, R., and Ridgway, S. 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? Journal of Theoretical Biology. 213:183-195.

Hu, S., Townsend, D.W., Chen, C., Cowles, G., Beardsley, R.C., Ji, R., and Houghton, R.W. 2008. Tidal pumping and nutrient fluxes on Georges Bank: A process-oriented modeling study. Journal of Marine Systems. 74:528-544.

Huntington, C.E., Butler, R.G., and Mauck, R.A. 1996. Leach's Storm-Petrel (*Oceanodroma leucorhoa*). IN The Birds of North America, No. 233. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 1999. Recommendation by ICCAT to establish a rebuilding plan for Western Atlantic bluefin tuna. IN ICCAT Report for biennial period, 1998-99. Part 1:Annex 5-7.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2000. Recommendation by ICCAT to establish a rebuilding program for North Atlantic wwordfish in report for biennial period, 1998-99. Part II:Annex 5-2.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2005. Report of the 2004 ICCAT bigeye tuna stock assessment session. Coll. Vol. Sci. Pap. ICCAT. 58:1-110.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2007. 2006 ICCAT workshop on swordfish stock structure. Coll. Vol. Sci. Pap. ICCAT. 61.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009a. Report of the 2009 Atlantic swordfish stock assessment session. ICCAT SCRS/2009/016.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009b. Report of the 2008 Atlantic bluefin stock assessment session. Col. Vol. Sci. Pap. ICCAT. 64.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009c. Report of the 2008 ICCAT yellowfin and skipjack stock assessments meeting. Coll. Vol. Sci. Pap. ICCAT. 64.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009d. Report for biennial period, 2008-2009. ICCAT SCRS Part I, Vol. 2.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009e. Report of the 2009 ICCAT albacore stock assessment session. ICCAT SCRS 2009-09.

Incze, L. 1998. Hypsometric characterization of the Gulf of Maine, Georges Bank, Scotian Shelf and neighboring continental slope. Gulf of Maine Area Program, Census of Marine Life. Website <http://www.gulfofmaine-census.org/about-the-gulf/physical-characteristics/bathymetry/hypsometric-characterization-of-the-gulf-of-maine-georges-bank-scotian-shelf/> (cited 1 December 2010).

IUCN 2010. IUCN Red list of threatened species. Version 2010.1. Website <www.iucnredlist.org> (cited 23 April 2010).

Jacobson, L.D. 2005. Essential fish habitat source document: Longfin inshore squid, *Loligo pealeii*, life history and habitat characteristics, 2nd Edition. NOAA Tech. Memo. NMFS-NE-193. 52pp.

James, M.C. and Herman, T.B. 2001. Feeding of *Dermochelys coriacea* on medusae in the Northwest Atlantic. Chelonian Conservation and Biology. 4:202-205.

James, M.C., Myers, R.A., and Ottensmeyer, C.A. 2005a. Behaviour of leatherback sea turtles, *Dermochelys coriacea*, during the migratory cycle. Proceedings of the Royal Society of London (B). 272:1547-1555.

James, M.C., Ottensmeyer, C.A., and Myers, R.A.. 2005b. Identification of high-use habitat and threats to leatherback sea turtles in northern waters: New directions for conservation. Ecological Letters. 8:195-201.

James, M.C., Sherrill-Mix, S.A., Martin, K., and Myers, R.A. 2006. Canadian waters provide critical foraging habitat for leatherback turtles. Biological Conservation. 133:347-357.

James, M.C., Sherrill-Mix, S.A., and Myers, R.A. 2007. Population characteristics and seasonal migrations of leatherback sea turtles at high latitudes. Marine Ecology Progress Series. 337:245-254.

Jensen, C.F., Natanson, L.J., Pratt, H.L., Kohler, N.E., and Campana, S.E. 2002. The reproductive biology of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. Fishery Bulletin. 100:727-738.

Ji, R., Cabell, D., Changseng, C., Townsend, D., Mountain, D., and Beardsley, R. 2008. Modeling the influence of low-salinity water inflow on winter-spring phytoplankton dynamics in the Nova Scotian Shelf-Gulf of Maine region. Journal of Plankton Research. 30:1399-1416.

Johnson, D.L., Morse, W.W., Berrien, P.L., and Vitaliano, J.J. 1999. Yellowtail flounder, *Limanda ferruginea*, life history and habitat characteristics. Essential fish habitat source document. NOAA Tech.Mem. NMFS-NE-140. 38pp.

Johnson, A.K., Richards, R.A, Cullen, D.W., and Sutherland, S.J. 2008. Growth, reproduction, and feeding of large monkfish, *Lophius americanus*. ICES Journal of Marine Science. 65:1305-1315.

Joyce, W.N., Campana, S.E., Natanson, L.J., Kohler, N.E., Pratt, H.L.Jr., and Jensen C.F.. 2002. Analysis of stomach contents of the porbeagle shark (*Lamna nasus* Bonnaterre) in the northwest Atlantic. ICES Journal of Marine Science. 59:1263-1269.

Kane, J. 2007. Zooplankton abundance trends on Georges Bank, 1977–2004. ICES Journal of Marine Science. 64: 909–919.

Kanwit, J.K. 2007. Tagging results from the 2000-2004 federal experimental fishery for Atlantic halibut (*Hippoglossus hippoglossus*) in the eastern Gulf of Maine. Journal of Northwest Atlantic Fishery Science. 38:37-42.

Katona, S.K., Rough, V.R., and Richardson, D. 1993. A field guide to the whales and weals from Cape Cod to Newfoundland, 4th Edition (revised). Smithsonian Institution Press, Washington, D.C. 316pp.

Kenchington, E.L., Harding, G.C., Jones, M.W., and Prodohl, P.A. 2009. Pleistocene glaciation events shape genetic structure across the range of the American lobster, *Homarus americanus*. Molecular Ecology. 18:1654-1667.

Kenney, R.D. and Winn, H.E. 1986. Cetacean high use habitats of the Northeast United States continental shelf. Fishery Bulletin. 84:107-114.

Kenney, R.D., Scott, G.P., Thompson, T.J., and Winn, H.E. 1997. Estimates of prey consumption and trophic impacts of cetaceans in the USA northeast continental shelf ecosystem. Journal of Northwest Atlantic Fishery Science. 22:155-171.

Kiraly, S., Moore, J., and Jasinski, P. 2003. Deepwater and other sharks of the US Atlantic Ocean Exclusive Economic Zone. Marine Fisheries Review. 65:1-63.

Klein-MacPhee, G. 2002. Atlantic cod/*Gadus morhus* Linnaeus 1758. IN Bigelow and Schroeder's Fshes of the Gulf of Maine, 3rd Edition. Collette, B.B. and Klein-MacPhee, G. (eds.). Smithsonian Institution Press, Washington, D.C. 235-242

Knowlton, A.R., Kraus, S.D., and Kenney, R.D. 1994. Reproduction in North Atlantic right whales (*Eubalaena glacialis*). Canadian Journal of Zoology. 72:1297-1305.

Kohler, N.E., Turner, P.A., Hoey, J.J., Natanson, L.J., and Briggs, R. 2002. Tag and recapture data for three pelagic shark species: Blue shark (*Prionace glauca*), shortfin mako (*Isurus xyrinchus*), and porbeagle (*Lamna nasus*) in the north Atlantic ocean. Col. Vol. Sci. Pap. ICCAT. 54. 1231-1260.

Kostylev, V.E. and Hannah, C.G. 2007. Process-driven characterization and mapping of seabed habitats. IN Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47. Todd, B.J. and Greene, H.G. (eds.). 171-184.

Kostylev V.E., Todd, B.J., Longva, O., and Valentine, P.C. 2005. Characterization of benthic habitat on Northeastern Georges Bank, Canada. American Fisheries Society Symposium. 41:141-152.

Kraus, S.D. and Rolland, R.M. 2007. Right whales in the Urban Ocean. IN The Urban Whale: North Atlantic Right Whales at the Crossroads. Kraus, S.D and Rolland, R.M. (eds.). Harvard University Press, Cambridge. 576pp.

Kraus, S.D., Prescott, J.H., Knowlton, A.R. and Stone, G.S. 1986. Migration and calving of right whales (Eubalaena glacialis) in the western North Atlantic. Report of the International Whaling Commission (Special Issue). 10:139-144.

Lai, D.Y. and Richardson, P.L. 1977. Distribution and movement of Gulf Stream rings. Journal of Physical Oceanography. 7:670-683.

Langton, R.W. 1983. Food habits of yellowtail flounder, *Limanda ferruginea* (Storer), from off the northeastern United States. Fishery Bulletin. 81:15-22.

Lawson, J.W. and Gosselin, J.-F. 2009. Distribution and preliminary abundance estimates for cetaceans seen during Canada's marine megafauna survey - a component of the 2007 TNASS. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/031. 34pp.

Le Gall, J.Y. 1974. Exposé synoptique des données biologiques sur le germon *Thunnus alalunga* (Bonaterre, 1788) de l'Océan Atlantique. Synopsis FAO sur les pêches, 109.

Legault, C.M., Alade, L., and Clark, K.J. 2009. Stock assessment of Georges Bank yellowtail flounder. TRAC Res. Doc. 2009/03.

Li, W.K.W., Harrison, W.G., and Head, E.J.H. 2006. Coherent sign switching in multiyear trends of microbial plankton. Science. 311:1157-1160.

Li, W.K.W, Sieracki, M.E., Rooney-Varga, J.N., Martin, J.L., Wilson, W.H., Gifford, D.J., Pilskaln, C.H. Andersen, R.A., and Incze, L.S. 2009. Planktonic microbes in the Gulf of Maine area. Census of Marine Life: Gulf of Maine microbial communities working group report. Gulf of Maine Science Symposium, St. Andrews, New Brunswick.

Lien, O.J. and Grimmer, L. 1978. Manx Shearwaters nesting in Newfoundland. Osprey. 9:50-54.

Limeburner, R. and Beardsley, R.C. 1996. Near-surface recirculation over Georges Bank. Deep Sea Research II. 43:1547-1574.

Link, J. 2002. Does food web theory work for marine ecosystems? Marine Ecology Progress Series. 230:1-9.

Link, J. 2004. Using fish stomachs as samplers of the benthos: integrating long-term and broad scales. Marine Ecology Progress Series. 269:265-275.

Link, J., Almeida, F., Valentine, P., Auster, P., Reid, R., and Vitaliano, J. 2004. The effect of area closures on Georges Bank. IN Benthic Habitats and the Effects of Fishing. Barnes, P. and Thomas, J. (eds). American Fisheries Society, Bethesda, Maryland.

Link, J.S., O'Reilly, J., Dow, D., Fogarty, M., Vitaliano, J., Legault, C., Overholtz, W., Green, J., Palka, D., Guida, V., and Brodziak, J. 2008. Comparisons of the Georges Bank ecological network: EMAX in historical context. Journal of Northwest Atlantic Fishery Science. 39:83-101.

Lock, A.R., Brown, R.G.B., and Gerriets, S.H. 1994. Gazetteer of Marine Birds in Atlantic Canada. Canadian Wildlife Service, Ottawa, Ontario.

Loder, J.W., Brickman, D., and Horne, E.P.W. 1992. Detailed structure of currents and hydrography on the northern side of Georges Bank. Journal of Geophysical Research. 97:14331-14351.

Loder, J.W., K.R. Drinkwater, N.S. Oakey and E.P.W. Horne. 1993. Circulation, hydrographic structure and mixing at tidal fronts: the view from Georges Bank. Phil. Trans. R. Soc. London. 343: 447-460.

Loder, J.W., Hannah, C.G., Shen, Y. Gonzalez, E., and Xu, Z. 1998. Suspended sediment drift and dispersion on Georges Bank. Can. Tech. Rep. Hydro. Ocean Sci. 188pp.

Loder, J.W., Hannah, C.G., Petrie, B.D., and Gonzalez, E.A. 2003. Hydrographic and transport variability on the Halifax section. Journal of Geophysical Research. 108:8003-8021.

Lough, R.G. and Manning, J.P. 2001. Tidal-front entrainment and retention of fish larvae on the southern flank of Georges Bank. Deep-Sea Research II. 48:631-644.

Lough, R.G., Bolz, G.R., Pennington, M., and Grosslein, M.D. 1985. Larval abundance and mortality of Atlantic herring (Clupea harengus L.) spawned in the Georges Banks and Nantucket Shoals areas, 1971–1978 seasons, in relation to spawning stock size. Journal of Northwest Atlantic Fishery Science. 6:21-35.

Lough G., Valentine, P., Potter, D., Auditore, P., Bolz, G., Neilson, J., and Perry, I. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series. 56:1-12.

Lough, G.R. (ed.). 2004. Essential fish habitat source document: Atlantic cod, *Gadus morhus*, life history and habitat characteristics, 2nd EditionNOAA Tech. Mem. NMFS-NE-190. 104pp.

Lutcavage, M.E., Brill, R.W., Skomal, G.B., Chase, B.C., and Howey, P.W. 1999. Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: Do North Atlantic bluefin tuna spawn in the mid-Atlantic? Canadian Journal of Fisheries and Aquatic Sciences. 56:173-177.

Lux, F.E. 1963. Identification of New England yellowtail flounder groups. Fishery Bulletin. 63:1-10.

Lynch, D.R., Gentleman, W.C., McGillicuddy, D.J., and Davis, C.S. 1998. Biological/physical simulations of *Calanus finmarchicus* population dynamics in the Gulf of Maine. Marine Ecology Progress Series. 169:189-210.

Maciolek, N.J. and Grassle, J.F. 1987. Variability of the benthic fauna. The seasonal variation 1981-82. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 303-309.

Magnusson, J.V., Bergstad, O.A., Hareide, N.R., Magnusson, J., and Reinert, J. 1997. Ling, Blue Ling and Tusk of the Northeast Atlantic. Tema Nord 535.

MarineBio. 2006. Carretta caretta, Loggerhead Sea Turtle. Website <http://marinebio.org/species.asp?id=163> (cited 2 February 2010).

Maurer, D. 1983. Review of benthic invertebrates of Georges Bank in relation to gas and oil exploration with emphasis on management implications. National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts, Lab. Ref. Doc. 83-16. 329.

Maurer, D. and Leathem, W. 1980. Dominant species of polychaetous annelids of Georges Bank. Marine Ecology Progress Series. 3:135-144.

Maurer, D. and Leathem, W. 1981a. Ecological distribution of polychaetous annelids from the New England Shelf, Georges Bank. International Review of Hydrobiology. 66:505-528.

Maurer. D. and Leathem. W. 1981b. Polychaete feeding guilds from Georges Bank, USA. Marine Biology. 62:161-171.

Mayo, R.K. 1998. Pollock. IN Status of Fishery Resources off the Northeastern United States for 1998. Clark, S.H. (ed.). NOAA Tech. Memo. NMFS-NE-115:67-69.

Mayo, C.A. and Marx, M.K. 1990. Surface foraging behavior of the North Atlantic right whale, *Eubalaena glacialis*, and associated zooplankton characteristics. Canadian Journal of Zoology. 68:2214–2220.

Mayo, R.K. and Terceiro, M. 2005. Assessment of the 19 Northeast groundfish stocks through 2004. Northeast Fish. Sci. Cent. Ref. Doc. 05-13.

Mayo, R.K., McGlade, J.M., and Clark, S.H. 1989. Patterns of exploitation and biological status of pollock (*Pollachius virens*) in the Scotian Shelf, Georges Bank and Gulf of Maine area. Journal of Northwest Atlantic Fishery Science. 9:13-16.

Mayo, R.K., Broadziak, J.K.T., Burnett, J.M., Traver, M.L., and Col, L.A. 2007. The 2005 assessment of Acadian redfish, Sebastes fasciatus Storer, in the Gulf of Maine/GeorgesBank Region. Northeast Fish. Sci. Cent. Ref. Doc. 07-06.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M-N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J., and McCabe, K. 2000a. Seismic surveys: analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Australian Petroleum Production Exploration Association, Western Australia.

McCauley, R.D., Duncan, A.J., Penrose, J.D., Fewtrell, J., Jenner, C., Prince, R.T., Murdoch, J., and Adhitya, A. 2000b. Marine Seismic Surveys - a study of environmental implications. Australian Petroleum Production Exploration Association Journal.

McEachern, J.D. 2002. Skates. Family Rajidae. IN Bigelow and Schroeder's Fishes of the Gulf of Maine, 3rd edition. Collette, B.B. and Klein-MacPhee, G. (eds.). Smithsonian Institution Press. Washington D.C. 60-75.

McEachern J.D, Boesch, D.F., and Musick, J.A. 1976. Food division within two sympatric species-pairs of skates (Pisces: Rajidae). Marine Biology. 35:301-317.

McRuer, J., Halliday, R.G., Bramton, R.M., Showell, M.A., and Mohen, R. 1997. Status of witch flounder in Div 4VWX in 1997. DFO Can. Stock Assess. Sec. Res. Doc. 97/106. 41pp.

McRuer, J., Hurlbut, T., and Morin, B. 2000. Status of Wolffish (*Anarhichas lupus*) in the Maritimes (NAFO SubArea 4 and Division 5Ze). DFO Can. Stock Assess. Sec. Res. Doc. 2000/138. 55pp.

Melvin, G.D. and Stephenson, R.L. 2007. The dynamics of a recovering fish stock: Georges Bank herring. ICES Journal of Marine Science. 64:69–82.

Melvin, G.D., Stephenson, R.L., and Power, M.J. 2009. Oscillating reproductive strategies of Atlantic herring in response to changing environmental conditions. ICES Journal of Marine Science. 66:1784-1792.

Metaxas, A. and Davis, J. 2005. Megafauna associated with assemblages of deep-water gorgonian corals in Northeast Channel, of Nova Scotia, Canada. Journal of the Marine Biological Association of the United Kingdom. 85:1381-1390.

Methratta, E.T. and Link, J.S. 2006. Associations between surficial sediments and groundfish distributions in the Gulf of Maine–Georges Bank region. Norther American Journal of Fisheries Management. 26:473-489.

Michael, A.D., Long, C.D., Maurer D, and McGrath, R. 1983. Georges Bank benthic infauna historical study. Final Rep. to U.S. Dept of the Interior, Minerals Management Service, Washington, D.C. 171.

Middleton, J.F. and Loder, J.W. 1989. Skew fluxes in polarized wave fields. Journal of Physical Oceaongraphy. 19:68-76.

Miller C.B., Lynch, D.R., Carlotti, F., Gentleman, W., and Lewis, C.V.W. 1998. Coupling of an individual-based population model of *Calanus finmarchicus* to a circulation model for the Georges Bank region. Fisheries Oceanography. 7:219-234.

Mitchell, E. and Chapman, D. G. 1977. Preliminary assessment of stocks of northwest Atlantic sei whales (*Balaenoptera borealis*). Report of the International Whaling Commission (Special Issue). 1:117-120.

Moody, J.A., Butman, B., Beardsley, R.C., Brown, W.S., Daifuku, P., Irish, J.D., Mayer, D.A., Mofjeld, H.O., Petrie, B., Ramp, S., Smith, P., and Wright, W.R. 1984. Atlas of tidal elevation and current observations on the Northeast American continental shelf and slope. United States Geological Survey Bulletin. 1611.

Mortensen, P.B. and Buhl-Mortensen, L. 2004. Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Marine Biology. 144:1223-1238.

Mortensen, P.B., Buhl-Mortensen, L., Gass, S.E., Gordon, D.C.Jr., Kenchington, E.L.R., Bourbonnais, C., and MacIsaac, K.G. 2006. Deep-water corals in Atlantic Canada: A summary of ESRF-funded research (2001-2003). Environmental Studies Research Fund Report No. 143.

Mowbray, T.B. 2002. Northern Gannet (Morus bassanus). IN The Birds of North America, No. 693. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Mrosovsky, N., Ryan, G., and James, M.C. 2009. Leatherback turtles: the menace of plastic. Marine Pollution Bulletin. 58:287-289.

Murua, H. and Saborido-Rey, F. 2003. Female reproductive strategies of marine fish species of the North Atlantic. Journal of Northwest Atlantic Fishery Science. 33:23-31.

Muschenheim, D.K. and Milligan, T.G. 1998. Benthic boundary layer processes and seston modification in the Bay of Fundy (Canada). Vie et Milieu. 48:285-294.

Myrberg, A.A.Jr. 2001. The acoustical biology of elasmobranchs. Environmental Biology of Fishes. 60:31-46.

Naimie, C.E. 1995. Georges Bank bimonthly residual circulation - prognostic numerical model results. Numerical Methods Laboratory, Dartmouth College, Hanover, New Hampshire. Rep No. NML-95-3. 33pp.

Naimie, C.E. 1996. Georges Bank residual circulation during weak and strong stratification periods - Prognostic numerical model results. Journal of Geophysical Research. 101:6469-6486.

Naimie, C.E., Loder, J.W., and Lynch, D.R. 1994. Seasonal variation of the three-dimensional residual circulation on Georges Bank. Journal of Geophysical Research. 99:5967- 5989.

Naimie, C.E., Limeburner, R., Hannah, C.G., and Beardsley, R.C. 2001. On the geographic and seasonal patterns of the near-surface circulation on Georges Bank – from real and simulated drifters. Deep-Sea Research II. 48:501-518.

NDPSWG (Northeast Data Poor Stocks Working Group). 2009. The northeast data poor stocks working group report: Part A. skate species complex, deep sea red crab, Atlantic wolffish, scup, and black sea bass. December 8-12, 2008. Northeast Fish. Sci. Cent. Ref. Doc. 09-02. 38pp.

NEFSC (Northeast Fisheries Science Center). 2006a. 43rd northeast regional stock assessment workshop (43rd SAW): 43rd SAW assessment summary report. NEFSC Ref Doc. 06-14. 54pp.

NEFSC (Northeast Fisheries Science Center). 2006b. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) stock assessment report, part A: silver hake, Atlantic mackerel, and northern shortfin squid. Northeast Fish. Sci. Cent. Ref. Doc. 06-09a. 608pp.

NEFSC (Northeast Fisheries Science Center). 2007. 44th SAW Stock Assessment Report. Northeast Fish. Sci. Cent. Ref. Doc. 07-10. 36pp.

NEFSC (Northeast Fisheries Science Center). 2009. Ecosystem assessment report for the Northeast U.S. continental shelf large marine ecosystem. Ecosystem Assessment Program, Northeast Fish Sci Cent Ref Doc. 09-11.

Neilson, J.D. and Perley, P. 1996. Can ichthyoplankton data be used to describe spawning areas of marine fish? IN Report of the Second Workshop on Scotia-Fundy Groundfish Management. Burke, D.L, O'Boyle, R.N., Partington, P., and Sinclair. M. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2100. 129-146.

Neilson, J.D., Hurley, P., and Perry, R.I. 1986. Stock structure of yellowtail flounder in the Gulf of Maine area: implications for management. CAFSAC Res. Doc. 86/64. Canadian Department of Fisheries and Oceans, Ottawa, Ontario.

Neilson, J.D., Perley, P., Carruthers, E.H., Stobo, W., and Clark, D. 2003. Stock structure of pollock in NAFO Divs. 4VWX5Zc. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/045. 55pp.

Neilson, J.D., Stobo, W.T., and Perley, P. 2006. Pollock (*Pollachius virens*) stock structure in the Canadian Maritimes inferred from mark-recaprure studies. ICES Journal of Marine Science. 63:749-765.

Neilson, J.D., Paul, S.D., and Smith, S.C. 2007. Stock structure of swordfish (*Xiphias gladius*) in the Atlantic: a review of the non-genetic evidence. Coll. Vol. Sci. Pap. ICCAT. 61:25-60.

Neilson, J.D., Smith, S., Royer, F., Paul, S.D., Porter, J.M., and Lutcavage, M. 2009. Investigations of horizontal movements of Atlantic Swordfish using pop-up satellite archival tags. IN Tagging and Tracking of Marine Animals with Electronic Devices, Reviews: Methods and Technologies in Fish Biology and Fisheries. Nielsen, J.L., Arrizabalaga, H., Fragoso, N., Hobday, A., Lutcavage, M., and Sibert, J. (eds.). Springer, Netherlands. 9:400pp.

Nelson, G.A. and Ross, M.R. 1992. Distribution, growth and food habits of the Atlantic Wolffish (*Anarhichas lupus*) from the Gulf of Maine – Georges Bank region. Journal of Northwest Atlantic Fishery Science. 13:53-61.

Nishikawa, Y., Honma, M., Ueyanagi, S., and Kikawa, S. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. Far Seas Fisheries Research Laboratory. 12pp.

NOAA (National Oceanic and Atmospheric Administration). 2006. Loggerhead Turtle (Caretta caretta). Website <www.nmfs.noaa.gov/pr/species/turtles/loggerhead .htm> (cited 2 February 2010).

NOAA (National Oceanic and Atmospheric Administration). 2008. Trends in spring conditions for the Georges Bank subregion, ecosystem advisory for the northeast shelf large marine ecosystem, no 2. Website <http://www.nefsc.noaa.gov/omes/OMES/spring2008/adv3.2.1.html> (cited 3 February 2010).

Nordeide J.T. and Kjellsby, E. 1999. Sounds from spawning cod at their spawning grounds. ICES Journal of Marine Science. 56:326–332.

O'Brien, L. and Worcester, T. 2009. Transboundary Resources Assessment Committee eastern Georges Bank cod benchmark assessment. TRAC Proceedings 2009/02.

O'Brien, L., Burnett, J., and Mayo, R.K. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA Tech. Rep. NMFS-NE-113. 72pp.

O'Dor, R.K. and Balch, N. 1985. Properties of *Illex illecebrosus* egg masses potentially influencing larval oceanographic distribution. NAFO Science Council Studies. 9: 69-76.

O'Hara, J. and Wilcox, J.R. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia. 2: 564-567.

Ohman M.D., Durbin, E.G., Runge, J.A., Sullivan, B.K., and Field, D.B. 2008. Relationship of predation potential to mortality of *Calanus finmarchicus* on Georges Bank, northwest Atlantic. Limnology and Oceanography. 53:1643-1655.

Oldham, W.S. 1966. Some aspects of the fishery and life history of the cusk (*Brosme brosme* (Muller). Master of Science Thesis, University of Western Ontario, London, Ontario. 86pp.

Oldham, W.S. 1972. Biology of Scotian Shelf cusk, *Brosme brosme*. International Commission for the Northwest Atlantic Fisheries Research Bulletin. 9:85-98.

O'Reilly, J.E. and Busch, D.A. 1984. Phytoplankton primary production of the northwestern Atlantic shelf. Rapports et Proces-Verbaux des Reunions. 183:255-268.

O'Reilly, J.E., Evans-Zetlin, C., and Busch, D.A. 1987. Primary Production. IN Georges Bank. Backus, R.A. and Bourne, D.W. (eds.). MIT Press, Cambridge, Masschussets. 220-233.

Overholtz, W.J., Jacobson, L.J., Melvin, G.D., Cieri, M., Power, M.J., Libby, D., and Clark, K. 2004. Stock assessment of the Gulf of Maine-Georges Bank herring stock complex, 2003. NFSC Ref. Doc. 04-06. 300pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003a. Essential fish habitat source document: Winter skate, *Leucoraja ocellatta*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-179. 68pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003b. Essential fish habitat source document: Little skate, *Leucoraja erinacea*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-175. 75pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003c. Essential fish habitat source document: Thorny skate, *Amblyraja radiata*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-178. 39pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003d. Essential fish habitat source document: Smooth skate, *Malacoraja senta*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-177. 26pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003e. Essential fish habitat source document: Barndoor skate, *Dipturus laevis*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-173. 23pp.

Page, F., Losier, R., Drinkwater, K., Petrie, B., Harrison, G., and Sameoto, D. 2001. Overview of the physical and biological oceanographic conditions on Georges Bank. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/66. 35pp.

Page, F.H., Losier, R., and Berrien P. 1998. Spawning time of haddock and cod on Georges Bank as indicated by the MARMAP ichthyoplankton data set. DFO Can. Stock Assess. Sec. Res. Doc. 97/130. 26pp.

Palka, D., Read, A., and Potter, C. 1997. Summary of knowledge of white-sided dolphins *(Lagenorhynchus acutus)* from the U.S. and Canadian North Atlantic waters. Report of the International Whaling Commission. 47:729-34.

Parent, S., Pepin, S., Genet, J-P., Misserey, L., and Rojas, S. 2008. Captive breeding of the barndoor skate, *Dipturus laevis*, at the Montreal Biodome, with comparison notes on two other captive-bred skate species. Zoo Biology. 27:145-153.

Payne, J.F., Andrews, C.A., Fancey, L.L., Cook, A.L., and Christian, J.R. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). Can. Tech. Report of Fish. Aquat. Sci. 2712. 53pp.

Payne, J.F., Andrews, C.A., Fancey, L.L., Guiney, J., Cook, A.L., and Christian, J.R. 2008. Are seismic surveys an important risk factor for fish and shellfish? Bioacoustics. 17:262-265.

Penttila, J.A. and Gifford, V.M. 1976. Growth and mortality rates for cod from the Georges Bank and Gulf of Maine areas. International Commission for the Northwest Atlantic Fisheries Research Bulletin. 12:29-36.

Pereira, J.G. 1995. Etat d'exploitation du stock de patudo. Collect. Vol. Sci. Pap, ICCAT. 44:272-280.

Pershing, A. J., Greene, C.H., Jossi, J.W., O'Brien, L., Brodziak, J.K.T., and Bailey, B.A. 2005. Interdecadal variability in the Gulf of Maine zooplankton community, with potential impacts on fish recruitment. ICES. Journal of Marine Science. 62:1511-1523.

Petrie, B.D. and Drinkwater, K.F. 1993. Temperature and salinity variability on the Scotian Shelf and in the Gulf of Maine 1945-1990. Journal of Geophysical Research. 98:20,079-20,089.

Pezzack, D.S. and Duggan, D.R. 1987. Canadian offshore lobster fishery, 1985-86, and assessment of the potential for future increases in catch. Can. Atl. Fish. Adv. Comm. Res. Doc. 87/79. 25pp.

Pezzack, D.S., Frail, C.M., Tremblay, M.J., and Reeves, A. 2009. Offshore lobster LFA 41 (4X and 5Zc). DFO Can. Sci. Advis. Sec. Res. Doc 2009/023. 124pp.

Pierotti, R.J. 1988. Associations between marine birds and mammals in the Northwest Atlantic Ocean. IN Seabirds and Other Marine Vertebrates. Burger, J. (ed.). Columbia University Press, New York. 31-58.

Pierotti, R.J. and Good, T.P. 1994. Herring gull (*Larus argentatus*). IN The Birds of North America, No. 124. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Pikanowski, R.A., Morse, W.W., Berrien, P.L., Johnson, D.L., and McMilliam, D.G. 1999. Essential fish habitat source document: Redfish, *Sebastes* spp., life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-132. 28pp.

Powers, K.D. and Brown R.G.B. 1987. Seabirds. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). The MIT Press, Cambridge, Massachusetts. 359-371.

Pratt, H.L. 1979. Reproduction in the blue shark, *Prionace glauca*. Fishery Bulletin. 77:445-470.

Reed, J.K. 2002. Deep-water *Oculina* coral reefs of Florida: biology, impacts, and management. Hydrobiologia. 471:43-55.

Reid, R., Almeida, F., and Zetlin, C. 1999. Essential fish habitat source document: Fishery independent surveys, data sources and methods. NOAA Tech. Mem. NMFS-NE-122. 39pp.

Richards, W.J. 1984. Kinds and abundances of fish larvae in the Caribbean Sea and adjacent areas. NOAA Technical Report NMFS-SSRF-776. 1-54.

Richards, W.J. 1969. Distribution and relative apparent abundance of larval tunas collected in the tropical Atlantic during Equalant surveys I and II. Proc. Symp. Oceanogr. Fish. Resourc. Trop. Atl.-Rev. Contrib. Pap. UNESCO, Paris, Pap. 25: 289-315.

Richards, R.A., Nitschke, P.C., and Sosebee, K.A. 2008. Population biology of monkfish *Lopius americanus*. ICES Journal of Marine Science. 65:1291-1305.

Ridderinkhof, H. and Loder, J.W. 1994. Lagrangian characterization of circulation over submarine banks with application to the outer Gulf of Maine. Journal of Physical Oceanography. 24:1184-1200.

Robards, M.D., Willson, M.F., Armstrong, R.H., and Piatt, J.F. 1999. Sand lance: a review of biology and predator relations and annotated bibliography. Res. Pap. PNW-RP-521. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Ronconi, R. 2007. The spectacular migration of greater shearwaters. Birdwatch Canada. 39:4-7.

Rooker, J.R., Secor, D.H., De Metrio, G., Schloesser, R., Block, B.A., and Neilson, J.D. 2008. Natal homing and connectivity in Atlantic bluefin tuna populations. Science. 322:742-744.

Rowe, S. and Hutchings, J. 2006. Sound production by Atlantic cod during spawning. Transactions of the American Fisheries Society. 135:529–538.

Royce, W.F., Buller, R.J., and Premetz, E.D. 1959. Decline of the yellowtail flounder (*Limanda ferruginea*) off New England. Fishery Bulletin. 59:169-267.

Rubega, M.A., Schamel, D., and Tracy, D.M. 2000. Red-necked phalarope (*Phalaropus lobatus*). IN The Birds of North America, No. 538. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Schrey, A. and Heist, E. 2003. Microsatellite analysis of population structure in the shortfin mako (*Isurus oxyrinchus*). Canadian Journal of Fisheries and Aquatic Sciences. 60:670-675.

Schuck, H.A. and Arnold, E.L. 1951. Comparison of haddock from Georges and Browns bank. Fishery Bulletin. 52:177-185.

Scott, J.S. 1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. Journal of Northwest Atlantic Fishery Science. 3:29-39.

Scott, W.B. and Scott, M.G. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences No. 219.

SFSC (Southeast Fisheries Science Center). 2009. An assessment of loggerhead sea turtles to estimate impacts of mortality reductions on population dynamics. NMFS Southeast Fisheries Science Center Contribution PRD-08/09-14, July, 2009, 46p.

Shepard, F.P., Trefethen, J.M., and Cohee, G.V. 1934. Origin of Georges Bank. Geological Society of America Bulletin. 45:281-302.

Sherman, K., Smith, W.G., Green, J.R., Cohen, E.B., Berman, M.S., Marti, K.A., and Goulet, J.R. 1987. Zooplankton production and the fisheries of the Northeastern Shelf. IN Georges Bank. Backus R.A. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 268-282.

Sherrill-Mix, S.A., James, M.C., and Myers, R.A. 2008. Migration cues and timing in leatherback sea turtles. Behavioral Ecology. 19:231-236.

Shirihai, H.,0 and Jarrett, B. 2006. Whales Dolphins and Other Marine Mammals of the World. Princeton University Press, Princeton, New Jersey. 384pp.

Shoop, C.R. and Kenney, R.D. 1992. Seasonal distributions and abundances of sea turtles off the northeastern United States. Herpetological Monographs. 6:43-67.

Sieburth J.M., Smetecek, V., and Lenz, J. 1978. Pelagic ecosystem structure: Heterotrophic compartments of plankton and their relationship to plankton size fractions. Limnology and Oceanography. 23:1256-1263.

Sigourney, D.B., Ross, M.R., Brodziak, J., and Burnett, J. 2006. Length at age, sexual maturity and distribution of Atlantic halibut, *Hippoglossus hippoglossus* L., off the Northeast USA. Journal of Northwest Atlantic Fishery Science. 36:81-90.

Simon, J.E. and Frank, K.T.. 1998. Assessment of the winter skate fishery in Division 4VsW. DFO Can. Stock Assess. Sec. Res. Doc.98/145. 41pp.

Simon, J.E., Harris, L.E., and Johnston, T.L. 2003. Distribution and abundance of winter skate, *Leucoraja ocellatta*, in the Canadian Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/028. 70pp.

Simon J.E., Cook, A., Rowe, S., and Simpson, M. 2009. Pre-COSEWIC review of barndoor skate (*Dipturus laevis*) in the Canadian Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/084. 93pp.

Sklepkovych, B.O. and Montevecchi, W.A. 1989. The world's largest documented colony of Leach's storm-petrels on Baccalieu Island, Newfoundland. American Birds. 43:36-42.

Smith, P.C. 1978. Low-frequency fluxes of momentum, heat salt and nutrients at the edge of the Scotian Shelf. Journal of Geophysical Research. 83:4079-4096.

Smith, P.C., Flagg, C.N., Limeburner, R., Fuentes-Yaco, C., Hannah, C.G., Beardsley, R.C., and Irish, J.D. 2003. Scotian Shelf crossovers during winter/spring 1999. Journal of Geophysical Research. 108:8013. 31pp.

Soldal, A.V., Midling, K.Ø., Fosseidengen, J.E., Svellingen, I., and Øvredal, J.T. 2000. Fish sound, a future tool for selectivity. Paper given at Fifth European Conference on Underwater Acoustics. Lyon, France, July 10-13, 2000.

Steele, J.H., Collie, J.S., Bisagni, J.J., Gifford, D.J., Fogarty, M.J., Link, J.S., Sullivan, B.K., Sieracki, M.E., Beet, A.R., Mountain, D.G., Durbin, E.G., Palka, D., and Stockhausen, W.T. 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. Progress in Oceanography. 74:423-448.

Stehlik, L.L. 1993. Diets of the brachyuran crabs Cancer irroratus, C. borealis and Ovalipes ocellatus in the New York Blight. Journal of Crustacean Biology. 13:723-735.

Stehilk, L.L., Mackenzie, C.L.Jr., and Morse, W.W. 1991. Distribution and abundance of four brachyuran crabs on the northwest Atlantic Shelf. Fishery Bulletin. 86:473-492.

Steimle, F.W., Morse, W.W., and Johnson, D.L. 1999. Essential fish habitat source document: Goosefish, *Lopius americanus*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-127. 40pp.

Steimle, F.W., Zetlin, C.A, and Chang, S. 2001. Essential Fish Habitat Source Document: Red Deepsea Crab, *Chaceon (Geryon) quinquedens*, Life History and Habitat Characteristics. NOAA Tech. Mem. NEFSC NMFS-NE-163. 36pp.

Stevenson, D.K. and Scott, M.L. 2005. Essential fish habitat source document: Atlantic herring, *Clupea harengus*, life history and habitat characteristics, 2nd Ed. NOAA Tech Memo NMFS-NE-192. 94pp.

Stoecker, D.K., Taniguchi, A. and Nichaels, A.E. 1989. Abundance of autotrophic, mixotrophic and heterotrophic planktonic ciliates in shelf and slope waters. Marine Ecology Progress Series. 50:241-254.

Stone, H.H. and Nelson, C. 2003. Tagging studies on eastern Georges Bank yellowtail flounder. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/056. 22pp.

Stone, H., Gavaris, S., Legault, C.M., Neilson, J.D., and Cadrin, S.X. 2004. Collapse and recovery of the yellowtail flounder (*Limanda ferruginea*) fishery on Georges Bank. Journal of Sea Research. 51:261-270.

Stone, H.H., Nelson, C., Clark, D., and Cook, A. 2009. 2008 Assessment of Pollock in 4VWX+5. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/001. 87pp.

Studholme, A.L., Packer, D.B., Berrien, P.L., Johnson, D.L., Zetlin, C.A., and Morse W.W. 1999. Essential fish habitat source document: Atlantic mackerel, *Scomber scombrus*, life history and habitat characteristics. NOAA Tech. Memo. NMFS-NE-141. 44pp.

Sulikowski, J.A., Morin, M.D., Suk, S.H., and Howell, W.H. 2003, Age and growth estimates of the winter skate (*Leucoraja ocellatta*) in the western Gulf of Maine. Fishery Bulletin. 101:405-413.

Sullivan B.K. and Meise, C.J. 1996. Invertebrate predators on Georges Bank, 1977-1978. Deep-Sea Research II. 43:1503-1519.

Swain, D.P., Simon, J.E., Harris, L.E., and Benoît, H.P. 2006. Recovery potential assessment of 4T and 4VW winter skate (*Leucoraja ocellata*): biology, current status and threats. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/003. 69pp.

TAWG (Turtle Assessment Working Group). 2007. An assessment of the leatherback turtle population in the Atlantic Ocean. NOAA Tech. Mem. NMFS-SEFSC-555. 116pp.

Templeman, W. 1985. Stomach contents of Atlantic Wolffish (*Anarhichas lupus*) from the Northwest Atlantic. NAFO Sci. Coun. Studies. 8:49-51.

Theroux, R.B. and Grosslein, M.D. 1987. Benthic fauna. IN Georges Bank. Backus, R. H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 283-295.

Theroux, R.B. and Wigley, R.L. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the Continental Shelf ecosystems of the Northeastern United States. NOAA Technical Report NMFS 140. 246pp.

Thomas, A., Townsend, D., and Weatherbee, R. 2003. Satellite-measured phytoplankton variability in the Gulf of Maine. Continental Shelf Research. 23:971-989.

Thomas, L., Hammill, M.O., and Bowen, W.D. 2007. Estimated size of the Northwest Atlantic grey seal population 1977-2007. DFO. Can. Sci. Advis. Sec. Res. Doc. 2007/082. 31pp.

Thompson, D. and Härkönen, T. 2008. *Phoca vitulina*. IUCN Red List of Threatened Species. Version 2009.2. Website <www.iucnredlist.org> (cited 3 February 2010).

Thouzeau, G., Robert, G., and Ugarte, R. 1991. Faunal assemblages of benthic megainvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Marine Ecology Progress Series. 74:61-82.

Tian, R.C., Chen, C., Stokesbury, K.D.E., Rothschild, B.J., Cowles, G.W., Xu, Q., Hu, S., Harris, B.P., and Marino, M.C.II. 2009. Modeling the connectivity between sea scallop populations in the Middle Atlantic Bight and over Georges Bank. Marine Ecology Progress Series. 380:147-160.

Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K., and Amend, M. 2006. Benthic invertebrates that form habitat structures on deep banks off southern California, with special reference to deep sea coral. Fishery Bulletin. 104:167-181.

Townsend, D.W., Thomas, A.C., Mayer, L.M., Thomas, M.A., and Quinlan, J.A. 2006. Oceanography of the Northwest Atlantic continental shelf (1,W). IN The Sea, Volume 14A. Robinson, A.R. and Brink, K.H. (eds.). Harvard University Press, Cambridge, Massachussetts. 119-168.

Townsend, D.W, Rebuck, N.D., Thomas, M.A., Karp-Boss, L., and Gettings, R.M. 2009. A changing nutrient regime in the Gulf of Maine. Gulf of Maine Symposium 2009: Advancing ecosystem research for the future of the Gulf. Oct. 4-9, 2009, St. Andrews, New Brunswick.

TRAC (Transboundary Resources Assessment Committee). 2009a. Gulf Of Maine-Georges Bank Herring Stock Complex. TRAC Status Report 2009/04. 6pp.

TRAC (Transboundary Resources Assessment Committee). 2009b. Eastern Georges Bank Cod. TRAC Status Report 2009/01. 7pp.

TRAC (Transboundary Resources Assessment Committee). 2009c. Eastern Georges Bank Haddock. TRAC Status Report 2009/02. 6pp.

TRAC (Transboundary Resources Assessment Committee). 2009d. Georges Bank yellowtail flounder. TRAC Status Report 2009/03. 8pp.

Tracy, D.M., Schamel, D., and Dale, J. 2002. Red Phalarope (*Phalaropus fulicarius*). IN The Birds of North America, No. 698. Poole A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Tremblay, M.J. and Sinclair, M. 1990. Sea scallop larvae *Placopecten magellanicus* on Georges Bank: vertical distribution in relation to water column stratification and food. Marine Ecology Progress Series. 61:1-15.

Tremblay, M.J., Loder, J.W., Werner, F.E., Naimie, C.E., Page, F.H., and Sinclair, M.M. 1994. Drift of seal scallop larvae *Placopecten magellanicus* on Georges Bank: A model study of the roles of mean advection, larval behavior and larval origin. Deep-Sea Research II. 41:7-49.

Trzcinski M.K., S.L. Armsworthy, S. Wilson, R.K. Mohn, and S.E. Campana. 2009. A framework for the assessment of the Scotian shelf and southern Grand Banks Atlantic Halibut Stock. Working Paper 2009/01.

Uchupi, E. and Bolmer, S.T. 2008. Geologic evolution of the Gulf of Maine region. Earth Science Reviews. 91:27-76.

Ullman, D.S., Dale, A.C., Hebert, D., and Barth, J.A. 2003. The front on the northern edge of Georges Bank in Spring, Part II: Cross-frontal fluxes and mixing. Journal of Geophysical Research. 108:8010. 14pp.

Uzmann, J.R., Cooper, R.A., Theroux, R.B., and Wigley, R.L. 1977a. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: submersible vs camera sled vs otter trawl. Marine Fisheries Review. 39:11-19.

Uzmann, J.R., Cooper, R.A., and Pecci, K.J. 1977b. Migration and dispersion of tagged American lobsters, *Homarus americanus*, on the southern New England continental shelf. Report NMFS-SSRF--705, Northeast Fish.Cent., NMFS, WoodsHole, MA, USA.

Valentine, P.C. and Lough, R.G. 1991. The sea floor environment and the fishery of eastern Georges Bank – the influence of geological and oceanographic environmental factors on the abundance and distribution of fisheries resources of the northeast United States continental shelf. U.S. Geological Survey, Open- File Report 91-439, Washington, D.C.

Veit, R. and Petersen, W. 1993. Birds of Massachusetts. Massachusetts Audubon Society, Lincoln.

Van Eeckhaute, L.A.M., Gavaris, S., and Trippel, E.A. 1999. Movements of haddock on eastern Georges Bank determined from a population model incorporating temporal and spatial detail. Fishery Bulletin. 97:661-679.

Walli, A., Teo, S.L.H., Boustany, A., Farwell, C.J., Williams, T., Dewer, H., Prince, E., and Block, B.A. 2009. Seasonal movements, aggregations and diving behavior of

Atlantic bluefin tuna (*Thunnus Thynnus*) revealed with archival tags. PLoS ONE 4:e6151.1

Wang, Y., O'Brien, L., Clark, K., Gavaris, S., and Hatt, B. 2009. Assessment of Eastern Georges Bank Atlantic Cod for 2009. TRAC Reference Document - 2009/01. 46pp.

Waring, G.T., Josephson, E., Fairfield, C.P., Maze-Foley, K (eds.). 2007. U.S. Atlantic and Gulf of Mexico barine bammal stock assessments - 2006. NOAA Tech Memo NMFS-NE-201. 388pp.

Waring G.T., Josephson E., Fairfield-Walsh C.P., Maze-Foley, K. (eds.). 2009. U.S. Atlantic and Gulf of Mexico marine mammal stock assessments - 2008. NOAA Tech Memo NMFS NE 210. 440pp.

Werner, F.E., Page, F.H., Lynch, D.R., Loder, J.W., Lough, R.G., Perry, R.I., Greenberg, D.A., and Sinclair, M.M. 1993. Influences of mean advection and simple behaviour on the distributions of cod and haddock early life stages on Georges Bank. Fisheries Oceanography. 2:43-64.

Whitehead, H., Bowen, W.D., Hooker, S.K., and Gowans, S. 1998. Marine Mammals. IN The Gully: A Scientific Review of Its Environment and Ecosystem. Harrison, W.G. and Fenton, D.G., (eds.). DFO Can. Stock Assess. Sec. Res. Doc. 98/83. 186-221.

Wiebe, P.H. and Beardsley, R.C. 1996. Physical-biological interactions on Georges Bank and its environs. Deep Sea Research II. 43:1437-1438.

Wiebe P.H., Beardsley, R.C., Mountain, D.G., and Bucklin, A. 2002. U.S. GLOBEC Northwest Atlantic/Georges Bank Program. Oceanography. 15:13-29.

Wiese, F. 2002. Seabirds and Atlantic Canada's Ship-source Oil Pollution. Toronto: World Wildlife Fund, Toronto, Ontario.

Wigley. R.L. 1961. Benthic fauna of Georges Bank. IN Transactions of the 26th North American Wildlife and Natural Resources Conference, March 6, 7, and 8, 1961. 310-317.

Wigley, S.E., Brodziak, J.K.T., and Col, L. 2003. Assessment of the Gulf of Maine and Georges Bank witch flounder stock for 2003. Northeast Fish. Sci. Cent. Ref. Doc. 03-14. 186pp.

Wise, J.P. 1958. The world's most indigenous cod. Journal du Conseil. 23:208-212.

Wishner K.F., Gifford, D.J., Sullican, B.K., Bisagni, J.J., Outram, D.M., and Van Keuren, D.E. 2003. Biological signature of Scotian Shelf Water crossovers on Georges Bank during spring 1997. Journal of Geophysical Research. 108:8014. 21pp.

Witt, M.J., Baert, B., Broderick, A.C., Formia, A., Fretey, J., Gibudi, A., Mounguengui, G.A., Moussounda, C., Ngouessono, S., Parnell, R.J., Roumet, D., Sounguet, G-Y., Verhage, B., Zogo, A., and Godley, B.J. 2009. Aerial surveying of the world's largest leatherback turtle rookery: a more effective methodology for large-scale monitoring. Biological Conservation.142:1719-1727.

Wolff, N. and Incze, L.S. 2009. Hypsometric characterization of the Gulf of Maine, Georges Bank, Scotian Shelf and neighbouring continental slope. Website <http://research.usm.maine.edu/gulfofmaine-census/about-the-gulf/physical-characteristics/bathymetry/hypsometric-characterization-of-the-gulf-of-maine-georges-bank-scotian-shelf> (cited 3 February 2010).

Xue, H., Chai, F., and Pettigrew, N. 2000. A model study of the seasonal circulation in the Gulf of Maine. Journal of Physical Oceanography. 30:1111-1135.

Xue, H., Incze, L., Xu, D., Wolff, N., and Pettigrew, N. 2008. Connectivity of lobster populations in the coastal Gulf of Maine. Part I: Circulation and larval transport potential. Ecological Modelling. 210:193-211.

Yano, K. 1995. Reproductive biology of the Black Dogfish, *Centroscyllium fabricii*, collected from the waters off western Greenland. Journal of the Marine Biological Association of the United Kingdom. 75:285-310.

Zeiber, R. 2008. Tagging 2008: A report on the Northeast regional tagging symposium. New Hampshire sea grant college program. October 17, 2008, Durham, New Hampshire. UNHMP-R-SG-09-02.

Zwanenburg, K.C.T., Bundy, A., Strain, P., Bowen, W.D., Breeze, H., Campana, S.E., Hannah, C.G., Head, E., and Gordon, D.G.Jr. 2006. Implications of ecosystem dynamics for the integrated management of the Eastern Scotian Shelf. DFO Can. Tech. Rep. Fish. Aquat. Sci. 2652. 106pp.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	**Range in Northwest Atlantic**	**Habitat**	**Relevance of Georges Bank to Species**	**Season**	**Diet**	**Abundance**	**Status**	**Known vulnerabilities**
Corals (ahermatypic)	North Atlantic	Benthic: shelf and slope	Northeast Channel Coral Conservation Area established (2002) within moratorium boundaries to protect high density of gorgonian corals. Provide complex habitat, feeding opportunities for aggregating species, hiding places, nursery and spawning sites for other species, and attachment substrate for fish egg cases and sedentary invertebrates	Year-round	Filter feeders-phytoplankton		Conservation area established 2002	Damage from bottom contacting activities. Ingestion of inorganic and organic contaminants in water and sediments
Sea scallop	Labrador to North Carolina	Benthic: coastal and shelf, sand, gravel 35-120 m	Very productive area with high growth rates. May have self-sustaining population: spawn May -June and Aug-Oct.	Year-round	Filter feeders-phytoplankton	Increasing (recruited adults)	No SARA or COSEWIC status	Ingestion of contaminants through filter feeding. Chronic contamination has sub-lethal effects on growth and reproduction; Settled animals vulnerable to growth inhibition by drilling muds
Lobster	Labrador to Maryland	Benthic: coastal and shelf	May have self sustaining population, some gene flow with Cape Cod and Southern Channel, Adults migrate onto plateau in summer to molt and mate, release eggs following summer.	Year-round	Larvae - zooplankton Adults -benthic invertebrates and fish	Increasing (recruited adults)	No SARA or COSEWIC status	Contaminants shown to have growth and developmental effects on larval pelagic phase as well as juvenile and adult lobsters. Larval pelagic phase vulnerable to water contaminants, with potential growth and developmental effects. High and low sound levels can affect feeding and serum biochemistry. Physical barriers prevent seasonal migrations.
Red crab	Nova Scotia to Florida	Benthic: shelf and slope 300-900 m	Large numbers of larvae collected over bank. These settle in deep water, migrating into shallower water as they mature. Egg bearing females found year round. Females occur more shallow than males.	Year-round	Larvae-zooplankton Adults opportunistic: benthic invertebrates, squid, demersal and pelagic fish species	Increasing	No SARA or COSEWIC status	No information
Jonah crab	Newfoundland to South Carolina	Benthic: shelf 50-300 m	May migrate onshore from spring to fall and offshore in winter. Spawning period in other areas late winter to early spring.	Year-round	Larvae - zooplankton Adults - opportunistic on benthic invertebrates, squid, demersal and pelagic fish	Declining	No SARA or COSEWIC status	No information

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
					species			
Northern Shortfin squid	Newfoundland to Florida	Pelagic: shelf and slope. Depth varies seasonally.	May be an important feeding ground during migration to/from Gulf of Maine in spring and fall.	Spring, Summer, Fall	Ontogenetic shift from crustaceans to fish and squid	Variable	No SARA or COSEWIC status	Sensitive to noise-alter behaviour 2-5 km from seismic source
Longfin squid	Georges Bank to North Carolina	Demersal by day, pelagic at night: shelf and slope. Depth varies seasonally.	Spawning on Georges Bank occurs late spring early summer.	Spring and Summer	Ontogenetic shift from plankton to crustaceans, small fish and squid	Variable; low relative to 1999-2002	No SARA or COSEWIC status	Sensitive to noise-alter behaviour 2-5 km from seismic source
Herring	Labrador to North Carolina	Pelagic: shelf and slope waters spring through fall	Adult portion of population over-winters South of Cape Cod, migrates onto Bank in summer for feeding and spawning. Spawning occurs along entire northern reach. Benthic spawners, demersal eggs hatch in 10-12 days, pelagic larvae 6 months; juveniles may migrate inshore in summer.	Adults: Summer and Fall; juveniles year-round	Plankton copepods, chaetognaths, krill	Increasing	No SARA or COSEWIC status	Spawns in relatively small and select locations: may be affected by disturbance and contaminants. Can detect broad range of sounds: if noise alters migration or spawning patterns, this would affect both herring and its several predators
Mackerel	Labrador to North Carolina	Pelagic: shelf and slope spring through fall	Spring and Fall migration over Georges Bank to/from spawning area in Gulf of St Lawrence. Juveniles and adults caught in RV surveys along sides of Bank, seldom on top.	Spring and Fall	Copepods, krill, shrimp, squid, fish	Declining, fewer older fish	No SARA or COSEWIC status	Pelagic eggs susceptible to contaminants. Lack of swim bladder reduces effect of sound pressure on animals
Sand lance	Greenland to North Carolina	Demersal by day; Pelagic by night; shelf	Species complex. Non-migratory. Burrow into substrate by day, vertically migrate nightly to feed in water column. Spawn November to March; demersal eggs; pelagic larvae until 35 mm length	Year-round	Larvae - phytoplankton, diatoms; Juveniles,	Variable recruitment and abundance	No SARA or COSEWIC status	Demersal eggs are vulnerable to bottom disturbance and contamination.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
					adults - copepods, polychaete larvae, krill, mysids, crabs			
Atlantic cod	Greenland to North Carolina	Demersal; coastal and shelf	Resident population with exchange with Browns Bank and Great South Channel. Northeast peak is an important nursery area for juveniles and is a habitat that provides an important food source.	Year-round	Larvae - phytoplankton, zooplankton; Juveniles, adults- crabs, molluscs, and fish (herring, sand lance)	Declining since 1990s, possible increase since 2005	No SARA status COSEWIC (2010) Endangered	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder may be part of courtship rituals. Life history of larval pelagic phase followed by demersal juveniles and adults with benthic feeding enhances susceptibility to contaminants in both water column and benthos and activities that disturb the bottom.
Haddock	Greenland to North Carolina	Demersal: 45-240 m; shelf	Resident population, seasonal migration to deeper water in summer. A major spawning concentration resides on the northern edge of the bank and Northeast Peak	Year-round	Larvae - phytoplankton, zooplankton; Juveniles and adults-benthic invertebrates crustaceans, molluscs, fish and echinoderms	Increasing	No SARA or COSEWIC status	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder may be part of courtship rituals. Life history of larval pelagic phase followed by demersal juveniles and adults with benthic feeding enhances susceptibility to contaminants in both water column and benthos and activities that disturb the bottom
Pollock	Labrador to North Carolina	Demersal; coastal and shelf to 380 m	Western component stock extends from Gulf of Maine to 4X portion of Scotian Shelf. Spawning on northeastern Georges Bank November-December; eggs and larvae present November to February.	Year-round	Juvenile- crustaceans and small fish Adult- euphausiids, squid and fish	Increasing since 2000	No SARA or COSEWIC status	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder. May be sensitive to excess noise.

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Monkfish	Newfoundland to North Carolina	Demersal: shelf; 70-190 m (>800 m)	Georges Bank population has northern and southern components, northern maybe continuous with Scotian Shelf. Seasonal onshore-offshore migrations. Peak spawning May-June.	Year-round	Larvae-zooplankton; Juveniles-fish, crustaceans; Adults- fish, crustaceans and squid	Declining	No SARA or COSEWIC status	No information
Cusk	North Atlantic	Demersal: shelf and slope to 600 m (1185 m max)	Occur mainly in Northeast Channel, on Northeast Peak, in Fundian Channel, also on Georges Bank. Spawning on Scotian Shelf occurs May-August.	Year-round	Invertebrates (crab and shrimp) and fish.	Declining	No SARA status COSEWIC (2003, 2006) Threatened	Vocalizations associated with aggressive behaviour, thus may be vulnerable to anthropogenic noise.
Redfish	Baffin Island to Gulf of Maine	Semi-pelagic: 100-700 m	Occur in the deep basins along the continental slope.	Year-round	Larvae -krill, copepods, fish and invertebrate eggs Adults: krill, mysids, fish	Increasing since 2001	No SARA status COSEWIC (2010) Threatened	Life history characteristics of late maturity and slow growth rates make this species susceptible to bottom activities causing disturbances.
Atlantic wolffish	Davis Strait to Massachusetts	Demersal: shelf; 22-275 m (350 m max)	Distributed throughout the Bank with concentrations found along the Northeast Peak and along the Great South Channel. Mature animals move inshore in summer. Spawn in September.	Year-round	Bivalves, echinoderms, gastropods and decapods	Declining	SARA Special Concern COSEWIC (2000) Special Concern	Nest spawning make the eggs susceptible to bottom activities causing disturbances or contamination.

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Atlantic halibut	Labrador to Virginia	Demersal: shelf and slope 200-500 m	Resident; seasonal migration to deeper waters in winter; extensive migrations throughout range.	Year-round	Ontogenetic shift from cephalopods, crustaceans and benthic invertebrates to fish	Declining	No SARA or COSEWIC status	No information
Yellowtail flounder	Labrador to North Carolina	Demersal: shelf; 37-73 m	Resident transboundary stock; benthic spawning late March-August; juveniles and adults concentrate on southern edge and northern peak in spring, throughout bank other seasons.	Year-round	Benthic invertebrates (amphipods, mysids, worms, sand dollars) and small fish	Increasing	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination.
Witch flounder	Labrador to North Carolina	Demersal: shelf and slope 50-300 m	Resident population, peak spawning May to August	Year-round	Benthic polychaetes, crustaceans, bivalves, echinoderms	Increasing	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination.
Winter skate	Newfoundland to North Carolina	Demersal: shelf; <1-371 m	Seasonal migration into shallow waters in summer. Georges Bank may be primary spawning ground for US population; Spawning occurs on Scotian shelf September to November	Year-round	Juveniles -sand shrimp, crabs, isopods, amphipods; Adults - invertebrates and fish	Variable; no trend	No SARA status COSEWIC (2005) Special Concern	Larval stage susceptible to bottom disturbance due to long incubation
Little skate	Scotian Shelf to Cape Hatteras	Demersal: shelf; <111 m (384 m max)	Widespread and abundant on Georges Bank, egg laying throughout year with peak in fall and winter.	Year-round	Decapod crustaceans, amphipods, polychaetes, fish	Variable; no trend	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Thorny skate	North Atlantic	Demersal: shelf <60 m	Uncommon on Georges Bank except in deeper portions of Northeast Peak, may be part of Gulf of Maine or Fundian Channel population.	Year-round, uncommon	Decapod crustaceans, amphipods, polychaetes, fish	Declining	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Smooth skate	Newfoundland to South Carolina	Demersal: shelf, >90 m	Uncommon on Georges Bank except in deeper portions of Northeast Peak, little information about life history.	Year-round	Amphipods, decapods, krill, mysids	Low abundance, no trend	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Barndoor skate	Labrador to North Carolina	Demersal: shelf, >1600 m	Population on Georges Bank restricted to southern portion of Georges Bank, may be continuous with Scotian Shelf population.	Year-round	Ontogenetic shift from shrimp, crabs to fish (sculpins, red hake, herring, ocean pout)	Variable, no trend	No SARA or COSEWIC status IUCN (2003) Endangered	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Spiny dogfish	Newfoundland to North Carolina	Bentho-pelagic: shelf	Migratory and resident populations in Northwest Atlantic; may be important mating area	Year-round	Invertebrates and fish	Decline since 1990s	No SARA status COSEWIC (2010) Special Concern	Life history characteristics of a long gestation period, low fecundity and growth rate make this species susceptible to increased mortality from sources including human activities. Attracted by high-level, low-frequency pulses, which may affect shark interactions and ability to detect prey
Black dogfish	Greenland to North Carolina	Bathy-demersal: slope	May occur at edges of Bank	Not known	Invertebrates (crustaceans, squid, jellyfish, cephalopods) and fish	Insufficient information	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: these may affect shark interactions and ability to detect prey
Swordfish	All North Atlantic (Newfoundland to Argentia)	Pelagic: shelf and slope; diving to depths of 800 m	Migrates onto Georges Bank, Northeast Peak is an important foraging area from June to October	Summer, Fall	Invertebrates (short-finned squid) and fish (barracudina, lanternfish, silver hake)	Increasing	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause swordfish to move to alternative foraging habitats
Bluefin tuna	All North Atlantic (Newfoundland to Gulf of	Pelagic: oceanic, < 200 m	Migrate onto Georges Bank June and July and remain until November. Important foraging habitat.	Summer, Fall	Juveniles -fish, squid, crustaceans;	Declining	No SARA status Under review by	Any activities disrupting behaviour of schooling prey species will cause bluefin tuna to move to alternative foraging habitats

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
	Mexico)				Adults – fish (herring, anchovy, sand lance, sardine, sprat, mackerel)		COSEWIC and CITES	
Yellowfin tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer, Fall	Fish and squid	Abundant	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause yellowfin tuna to move to alternative foraging habitats
Bigeye tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer, Fall	Fish, squid, krill	Declining	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause bigeye tuna to move to alternative foraging habitats
Albacore tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer	Fish (sardine, mackerel, anchovy), squid, and crustaceans	Declining	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause albacore tuna to move to alternative foraging habitat
Porbeagle shark	North Atlantic (Newfoundland to New Jersey)	Pelagic: shelf	Adults migrate over Georges Bank in summer; Important mating area with females congregating in preparation for mating in June.	Summer, Fall	Pelagic and demersal fish species, squid and shellfish	Decline: 25% of virgin population	No SARA status COSEWIC (2004) Endangered	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Thresher shark	Newfoundland to Cuba	Pelagic: shelf	Juveniles, adults migrate onto Georges Bank in summer.	Summer	Pelagic fish species, crustaceans, squid, octopi	Decline: 75% since 1986	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey.

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Basking shark	All North Atlantic	Pelagic: shelf	Migrate onto bank for feeding during summer and fall, may form mating congregations in summer.	Spring, Summer, Fall	Plankton	Decline in Canadian data, no trend in US data	No SARA status COSEWIC (2009) Special Concern Listed by CITES, IUCN	Low resilience to perturbation (collisions, bycatch); attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey.
Short-fin mako shark	All North Atlantic	Pelagic: shelf	Migrate into area during summer and fall.	Summer, Fall	Fish, sharks, turtles, marine mammals and squid	Decline since 1970	No SARA status COSEWIC (2006) Threatened	Low resilience to perturbation and exploitation; attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Blue shark	All North Atlantic (Newfoundland to Argentina)	Pelagic: shelf	Migrate into area during May to October	Spring, Summer, Fall	Pelagic and demersal fish species, invertebrates	Variable estimates: no change to decline since 1980s	No SARA status COSEWIC (2006) Special concern	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Hammerhead shark	Nova Scotia to Florida	Pelagic: shelf	Migrates into Canadian waters in summer, uncommon in Georges Bank.	Summer	Pelagic fish species (herring, menhaden), rays, skates, sharks, squids, crabs	Decline: 89% since 1986	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
White shark	Global but uncommon in North Atlantic	Pelagic: shelf	Infrequent occurrence in Atlantic Canada: migration into region in summer	Summer	Fish species and marine mammals	Decline: 80% since 1990	No SARA status COSEWIC (2006) endangered	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
North Atlantic right whale	Gulf of St Lawrence to Florida	Pelagic, shelf	Seasonal migrations over Bank in Spring and Fall, foraging area during Summer	Spring, Summer, Fall	Zooplankton (primarily *Calanus*)	Increase: 30% during last decade	SARA endangered COSEWIC (1980, 2003) endangered	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Fin whale	All Northwest Atlantic	Pelagic: shelf	Seen on Bank year-round but abundance fluctuates due to seasonal migrations from tropical wintering areas to temperate summer feeding grounds	Year-round	Pelagic fish species (herring, capelin) and squid, krill, mysids	Insufficient information	SARA Special Concern COSEWIC (1987, 2005) Special concern	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Sei whale	Labrador to Georges Bank	Pelagic: shelf edge, <2000 m	Occur year-round on Bank, higher concentration in Spring and Summer	Year-round	Zooplankton (copepods)	Insufficient information	No SARA status COSEWIC (2003) Data Deficient	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Minke whale	Davis Strait to Gulf of Mexico	Pelagic: shelf	Occur on Bank in Spring and Summer	Spring, Summer	Crustaceans, plankton and small pelagic fishes	Insufficient information	No SARA status COSEWIC (2006) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Humpback whale	Greenland to West Indies	Pelagic: coastal	Seasonal migrations over Bank in Spring and Fall, foraging area during Summer	Spring, Summer, Fall	Crustaceans, plankton and small fish	Increasing	SARA Special Concern COSEWIC (2003) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Sperm whale	Nova Scotia to Cape Hatteras	Pelagic: shelf and slope <1000 m	Males occur year-round on Bank, population distributed over southern portion of Georges Bank in Spring, northern and eastern portions in summer	Year-round	Mesopelagic and benthic squid and fish species	Insufficient information	No SARA status COSEWIC (1996) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Pilot whale	Western Atlantic	Pelagic: shelf and slope	All year, higher prevalence in spring-summer	Year-round	Squid species	Insufficient information	No SARA status COSEWIC (1994) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Bottlenose dolphin	Scotian Shelf to tropics	Pelagic: coastal and shelf	All year, higher prevalence in spring-summer	Year-round	Fish, squid and invertebrates	Insufficient information	No SARA status COSEWIC (1993) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
White-sided dolphin	Greenland to North Carolina	Pelagic: shelf	Present on Bank all year, lower abundance in winter	Year-round	Pelagic fish species (herring, sandlance, silver hake) and squid	Insufficient information	No SARA status COSEWIC (1991) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Common dolphin	Newfoundland to Cape Hatteras	Pelagic: shelf and slope	Range from Cape Hatteras to Georges Bank in January-May, move onto Bank and Scotian Shelf in summer, form large aggregations on Bank in fall and winter	Year-round	Pelagic fish species and cephalopods	Insufficient information	No SARA status COSEWIC (1991) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Striped dolphin	Georges Bank to Cape Hatteras	Pelagic: shelf and slope	Most prevalent in summer and fall	Summer, fall	Pelagic and demersal benthic fish species and cephalopods	Insufficient information	No SARA status COSEWIC (1993) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Harbour porpoise	Labrador to Bay of Fundy	Pelagic: coastal and shelf	Migrates over Georges Bank in spring and fall migrations to/from coastal feeding grounds	Spring: migration	Pelagic fishes (herring, sandlance, capelin) and cod	Insufficient information	SARA Threatened COSEWIC (2003) Special Concern	Entanglements, habitat degradation, acoustic harassment devices, environmental contaminants

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Blue whale	All North Atlantic (Davis Strait to Nova Scotia)	Pelagic: coastal and shelf	Uncommon occurrence on Georges Bank	Spring, Summer, Fall	Krill	Insufficient information	SARA Endangered COSEWIC (2002) Endangered	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Sowerby's Beaked whale	All North Atlantic (Davis Strait to Cape Cod)	Pelagic: shelf and slope	Uncommon occurrence, no known seasonal migrations	Not known	Pelagic and mesopleagic fish and squid species	Insufficient information	SARA Special concern COSEWIC 2006 Special concern	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Grey seal	All North Atlantic (Labrador to Gulf of Maine)	Pelagic: coastal and shelf 0-200 m	Sable Island population travels widely and forages on Georges Bank	Year-round	Fish, cephalopods, crustaceans and occasionally seabirds	Increasing	NO SARA status COSWEIC 1999 Not at risk	Susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion
Harbour seal	All North Atlantic	Pelagic: coastal and shelf	Occur seasonally on Georges Bank	Year-round	Fish, cephalopods and crustaceans	Increasing	No SARA status COSEWIC 2007 Not at Risk	Susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion
Leatherback turtle	Labrador to South America	Pelagic: coastal and shelf	Georges Bank area used for foraging April to December	Spring, Summer, Fall	Gelatinous zooplankton	Insufficient information	SARA Endangered COSEWIC 1981, 2001 Endangered	Entanglement in lines, vessel strikes, plastics ingestion, inferred potential disturbance from underwater sounds based on response of other turtle species to seismic surveys
Loggerhead turtle	Newfoundland to Argentina	Pelagic: coastal and shelf	Georges Bank area used for foraging July to October	Summer, Fall	Fish species and benthic invertebrates	Decline	No SARA status COSEWIC (2010) endangered	Entanglement in lines, vessel strikes, plastics ingestion, inferred potential disturbance from underwater sounds based on response of other turtle species to seismic surveys

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Greater Shearwater	All South and North America	Pelagic	Migrate from south American breeding grounds and appear on Georges Bank area in May and remain until November.	Summer, Fall	Fish, squid, crustaceans	Abundant	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; attracted to lights of offshore vessels and platforms
Red phalarope	North and South Atlantic	Pelagic	Arrive on Bank in May and feed for one month; southward migration across Bank in October	Spring, Fall	Plankton (copepods, krill, larval fish), insects	Declining	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas
Wilson's storm-petrels	All South and North America	Pelagic	Migrate from South American breeding grounds and appear on Georges Bank area in May, remain until October	Spring Summer, Fall	Amphipods, krill, squid, fish	Abundant	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; attracted to lights of offshore vessels and platforms
Thick-billed Murre	Circumpolar Artic (Greenland to Georges Bank)	Pelagic	Migrate southwards from Arctic breeding grounds and appear on Georges Bank December through May	Winter, Spring	Fish, crustaceans, squid and annelids	Stable	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; high mortality shown near Newfoundland shown to be due to chronic oil pollution
Northern Fulmar	Arctic to Georges Bank	Pelagic	Migrate southwards from Arctic breeding grounds, common on Georges Bank January through March but sighted year round.	Year-round (except August)	Fish, cephalopods and zooplankton	Stable	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas
Black legged Kittwake	Arctic Ocean to Georges Bank	Pelagic	Migrate south from breeding grounds in Arctic, Iceland and eastern Atlantic, and appear on Georges Bank October through April	Fall, Winter, Spring	Fish and invertebrates	Expanding except for Newfoundland colonies	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas: oil spills in Alaska killed thousands

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Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Northern gannet	Newfoundland to Florida	Pelagic	Southward migration from breeding grounds to wintering locations: abundant on Georges Bank from October to December and March through May	Fall, Spring	Fish	Increasing	No SARA or COSEWIC status IUCN: Least Concern	Not as directly affected by oil spills as other seabirds
Herring gull	Baffin Island to Cape Hatteras	Pelagic	Occur on Georges Bank year-round	Year-round	Fish, invertebrates, insects, other seabirds and eggs	Decline	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas
Great Black-backed gull	Florida to Hudson Strait	Pelagic	Immature birds common on Georges Bank in spring, also wintering area for northern breeding colonies	Spring, Winter	Fish, invertebrates, mammals, insects, other seabirds and eggs	Expanding except for Nova Scotia colonies	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas